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Transient Changes of Waveform of Event-Related Cerebral Potentials in Man during Selective Listening

Leif R. Hedman

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Transient Changes of Waveform of Event-Related Cerebral Potentials
in Man during Selective Listening

av

Leif R. Hedman

F.K., Lund

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26T0 The report is a summarizing introduction to a joined dissertation based on three scientific papers (appended to the report) in which Event Related Potentials (ERPs) and attention are studied. The first paper describes changes in the Average Evoked Potentials (AEPs) to tones when subjects' degree of attention towards "relevant" tones was altered between four different conditions. The second paper presents an investigation designed to replicate and extend the results of the previous investigation using synthetic speech stimuli and a memorizing task. The last paper describes a new process model of selective listening where an extended use of single-trial analysis is argued for.

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The dissertation consists of the present summary and the following three papers:

- (i) Hedman, L.R. (1975). Effects of attention distribution on auditory evoked potentials. Psychol. Res. Bull., Lund Univ., Sweden, 15, no. 8.
- (ii) Hedman, L.R. (1975). Selective attention and auditory evoked potentials in man. Psychol. Res. Bull., Lund Univ., Sweden, 15, no. 9.
- (iii) Hedman, L.R. (1977). Outline of a process model of listening: some implications for the study of event related potentials.

A c k n o w l e d g e m e n t s

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Transient Changes of Waveform of Event-Related Cerebral Potential in Man during Selective Listening

"Every one knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought".

William James
The principles of psychology, Vol. 1. 1890

At the present time computer methods are being used increasingly in the study of the cerebral potentials that are related to sensory, central and/or motor events (Event Related Potentials or ERPs). These powerful devices permit of quantification and detailed examination of various of the cerebrally generated electric events associated with cognitive functioning in human subjects.

The study of ERPs is developing fast and in several directions. Such an expanding and multidisciplinary field offers a promising source of correlative and convergent information for the study of attention.

The study reported in paper (i) describes an attempt to elucidate what kind of changes took place in a subject's ERPs when his degree of attention towards task-relevant tones was altered between four different experimental conditions: discrimination, rest and two types of distraction. In general, the results indicate that in the discrimination condition, i.e. when subjects were preoccupied with the listening to relevant tones, the peak-to-peak amplitudes of the so-called N_1 - P_2 , N_2 - P_3 and P_3 - N_3 wave complex, were all enhanced, whereas these same amplitudes were attenuated when subjects were engaged in distraction tasks. All latencies were stable except N_3

which was prolonged under discrimination as compared to other experimental conditions.

Thus, both early and late components of the ERP fluctuated in a systematic manner between conditions in this experiment. However, present results cannot confirm the reports which indicate equal effects for all components of the ERP (e.g. Schafer and Marcus, 1973), since the experimental paradigms are considerably different in the two experiments.

Furthermore, the amplitudes P_3-N_3 and especially N_2-P_3 were relatively small in all conditions except for the condition of discrimination in this study. Therefore these findings offer no evidence for a global change in the ERP waveform. Attempts to treat the ERP as a unitary phenomenon whose components respond in unison to experimental manipulations are unreasonable, since most data are in accordance with the view of the ERP as a sequence of components which respond in different ways to experimental manipulations (Picton et al., 1978; Tueting, 1978).

There is increasing evidence that ERPs reflect a number of cognitive variables in a systematic way. The modality-specific N_1 component appears to be related to early levels of selective attention, whereas the modality-nonspecific P300 wave - which must be considered endogenous since it can occur in the absence of an external stimulus under certain conditions - seems to be associated with the late stages of selective attention. A plethora of similar psychological constructs have been based on a unitary view of P300. However, an alternative view of the P300 as a complex phenomenon seems to be justified, since it has become increasingly clear that ERPs reflect both serial and parallel processes.

Paper (ii) presents an investigation that was mainly designed to determine if the findings reported previously could be replicated and extended by the use of (1) synthetic speech stimuli, and (2) a distraction task (memorizing). Previous results were completely re-

produced and the new, memorizing condition reduced ERPs most effectively. Identical changes took place in ERPs to synthetic speech stimuli as compared to pure tones in four experimental conditions. Since only the kind of event presented in these conditions varied between the experiments, the result indicates that the amplitudes of early and late ERP components fluctuated mainly as a function of task-variables.

There has been much controversy and discussion concerning the proper manner of relating psychological variables to ERP data. Sutton (1969) and Donchin (1973) have criticized attempts to interpret evoked potential data with the aid of poorly defined psychological terms. However, recent contributions to this field of study may offer more appropriate ways of interpreting brain potential data (Cooper, 1975; Desmedt, 1977; Donchin et al., 1977; Näätänen, 1975; Papakostopoulos, 1978; Picton et al., 1978; Tueting, 1978).

As Papakostopoulos points out, ERPs are products of the subject's brain, the experimenters interests and the level of available technology. If we concentrate upon the first two components we must specify the characteristics of the electrophysiologic events going on in the brain, as well as the specific levels of analysis which the experimenter employs in his description of the data.

The lack of a specific definition of the basic parameters of evoked potentials, i.e. rise time, amplitude and latency, is an important obstacle to the formulation of satisfactory functional models of the brain based upon human evoked potential data. As emphasized in paper (i) we know little about the reliability of amplitude measures. It is argued that for example, a given experimental condition may reveal a small average amplitude because of high peak-latency variability rather than a true decrease in peak-to-baseline amplitude (e.g. Ruchkin and Sutton, 1978). Besides, this smaller average amplitude may be due to differential changes in amplitude of specific ERP-components during successive trials in an experiment. One solution to this problem of the dependency between amplitude and

latency measures requires that we collect amplitude-, and latency distributions in a trial-to-trial manner, despite the considerable technical problems involved in single trial analysis (e.g. Weinberg, 1978).

It is also stated in paper (i) and (ii) that the recent emphasis placed on the functional significance of event related potentials based on their spatial distribution is another step towards better understanding. Moreover, instead of identifying ERP components with peak latencies in the waveform, it may be more appropriate to define the different components of the waveform in terms of the effects of experimental variables on their amplitude. Thus, it is well to emphasize that the ERPs to be interpreted are exclusively a property of the subject's brain - not the experimenter's.

But it is not enough that single trial analysis and scalp distribution study are used on their own as methods for investigating ERPs. They should rather be used as complimentary to multilevel analyses in which the simultaneous and consistent patterns of changes at subcortical-, spinal-, and peripheral systems during a given series of events are taken into account (e.g. McCallum et al., 1976; Papakostopoulos and Cooper, 1976, 1978). These methods used in conjunction with one another as well as some other experimental integrative approaches such as that of Lacey and Lacey (1970) and Ingvar (1975), are capable of describing activities in various bodily systems, ranging from cerebral blood flow, cortical and subcortical evoked potential, spinal reflex and heart rate changes, which occur during a specific experimental condition.

What a recording from only one cortical location gives is a sub-pattern of the total spatial pattern of changes. To complicate the issue further such patterns are also temporally distributed. At the same time as an evoked potential is recorded, other activities are going on in the brain, e.g. intrinsic rhythms, changes in membrane potentials and modulations of the pattern of neuronal connections (Scheibel and Scheibel, 1970; Skinner and Yngling, 1977). Moreover,

the findings of John and his collaborators (John et al., 1975; John and Pritchep, 1978; Thatcher and John, 1977) indicate that, as the brain state changes a particular physical stimulus elicits a variety of different evoked potential waveshapes. Thus, the stimulus which immediately precedes another, similar one in a sequence of stimuli seems to influence the ERP to the stimulus which comes after it. So the presumed "noise" which is eliminated from the set of ERPs by the averaging process may be an important and perhaps essential part of the signal. Recent visual evoked potential data (Pfurtscheller et al., 1977) seem to indicate that a given stimulus elicits event related changes in both the EP components and the background EEG activity.

Finally, by using chronically implanted subdural macroelectrodes it has been shown that (1) all the main types of macropotentials - intrinsic activity, sustained potentials, and evoked potentials - can be recorded from the same cortical electrode, (2) evoked potentials can differ in waveform when the readings are taken from brain locations which are situated only a few millimeters apart, and (3) specific components of the ERP - in particular the P300 - can be localized or generalized according to experimental condition - i.e. in the go and no-go paradigm (Papakostopoulos and Crow, 1976).

It may be seen from the foregoing that a general functional model of the brain should take into account the relationships of the spatiotemporal factors just mentioned in organismic space. Moreover, recent findings indicate that even subtle changes in experimental paradigm will alter the state of both the brain and other bodily systems (Papakostopoulos and Cooper, 1976, 1978).

A functional brain model should consider the multifactorial reality of brain potentials, in particular what Katchalsky et al. (1974) has referred to as the "dynamic pattern" of macropotential states. A specific event is represented in various local brain areas depending on the relative contribution of numerous factors within the "neurometric space" (John and Pritchep, 1978). Some investigators (e.g. Cooper et al., 1978) suggest that these factors might be

determined by the two modes of nervous function described in their bimodal slow potential theory of cerebral processing.

When studying ERPs, we must somehow quantify each factor and its spatiotemporal significance. In this endeavour we may be helped by using models at several levels of analysis. But within the multidisciplinary field of ERPs it seems inappropriate to initiate the model building and generation of hypotheses at the lowest levels of analysis, since interpretations at higher levels may support us in the generating of the proper hypotheses. Paper (iii) describes a new process model of selective listening which is based on psychological data. This model can be used to generate functional hypotheses which explain the fluctuations of ERPs. Simultaneously, established facts about brain potentials may constitute the basis for extrapolations to the psychological level.

Furthermore, it is argued in this paper that current information processing models of selective attention are both too simple and too static. Recent findings from research on auditory patterns and serial reaction times seem rather to support a complex and dynamic model of selective attention. This process model implies that auditory attention, instead of being a fixed mechanism that controls the flow of information, is a skill which is dependent on discrepancies between objective events and subjective structure, as e.g. reflected in the person's internalized subjective strategies of listening.

Sequential effects in reaction time data indicate that the subject may derive subjective probabilities from the objective microstructure of a recently presented serial pattern. One can conceive of at least three aspects of subjective strategy - the temporal repetition, event repetition and alternation strategies, which are updated in a trial-by-trial manner. It is reasonable to assume that serial changes in the subject's performance and in single brain potentials are concomitant with his ability to learn and adapt to the task of selective listening.

The implications for the study of average ERPs are clear. It seems unreasonable to propose that all single ERPs, associated with a particular event, are homogeneous. Furthermore, it is inappropriate to interpret ERP changes exclusively in terms of decision making during the discrimination of each event, since selective listening is an on-going decision process by which the subject interacts with the experimental environment.

The process model of selective listening suggested here appears to be consistent with recent functional models that consider the multifactorial reality of brain macropotentials. There is, furthermore, experimental evidence which suggests that the stimulus probability influences the generation of ERP, e.g. the P300 wave. However, generalizations about the P300 wave must be regarded as only tentative since they are based on a variety of experiments in which P300s of widely different latencies and scalp distributions have been observed.

Selective attention, uncertainty, information delivery, significance, salience, orienting and inhibition have each of them been proposed as the psychological factor which explains the P300 waveform (see Sutton et al., 1978). However, the current trend is to search for two or more independent P300. Scalp location has become the most favoured variable - rather than amplitude and latency - in arguments for the distinctness or unitary nature of the late positive waves. When the P300 wave is recorded in different locations on the scalp, 4 different types of anterior-posterior distributions have been observed (see Roth, 1978). But it does not follow that such distributions reflect several independent psychological processes. Therefore more data is needed concerning the effects of the various experimental variables on the late positive waves as well as ERP components in general.

The present process model of selective listening could be used to re-interpret previous findings of distinct P300s in terms of one complex P300 - several dependent P300s - whose anterior-posterior

amplitude distribution (and perhaps even latency distribution) varies from trial to trial with the development and e.g. differentiation of dynamic, subjective strategies. This pattern need not apply to a priori global strategies in a specific experimental situation. The model also implies that rigorous experimental paradigms are a sine qua non when one studies the spatio-temporal patterns of single ERPs.

The author suggests that in the next few years we shall see an increase in interest for single ERP studies on a large scale. Hopefully, this thesis will help in the effort to integrate future findings.

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*Effects of Attention Distribution on Auditory
Evoked Potentials*

by Leif R. Hedman



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A b s t r a c t . - Studied the waves of average evoked potentials (AEPs) for 20 subjects. 50 tones with intensity of 65 dB SPL and a duration of 300 milliseconds were presented binaurally and at random intervals under four differing conditions, which altered the individuals' degree of attention towards these stimuli. Conditions were: rest, discrimination and two kinds of distraction. The results indicate that both early and late AEPs - the amplitudes of N_1 - P_2 , N_2 - P_3 and P_3 - N_3 - were enhanced for discrimination and diminished for differing conditions of distraction relative to rest. The general process view of AEPs advanced here is discussed from methodological and conceptual aspects usually disregarded in the field of EP-research. It is argued that the differential changes of AEPs as found here, but the P_3 in particular, were effects of pre- and post-stimulus processes such as strategies and decisions, respectively.

This paper is concerned with systematic fluctuations of the average evoked potentials (AEPs) to auditory stimulation. A large number of studies have found that amplitudes of the N_1 (80-120 msec in latency) and the P_2 (160-200) waves are larger when subjects attend to task-relevant auditory stimuli, than when their attention is focused or directed elsewhere (i.e. Gross et al., 1965; Keating and Ruhm, 1971; Näätänen, 1967, exp.3; Satterfield, 1965; Spong et al., 1965; Wilkinson and Morlock, 1967).

In these studies, however, the subjects were able to predict the occurrence of relevant stimuli. Therefore, Näätänen (1967) remarked that the enhancement of N_1 - P_2 amplitudes might rather be explained by an increased alertness just before anticipated task-relevant stimuli, than by post-stimulus factors such as selective attention. Several other studies have tested the possibility of differential preparatory arousal or alertness by presenting series of relevant and irrelevant stimuli at random (i.e. Näätänen, 1967, exp.2; Smith et al., 1970; Wilkinson and Lee, 1972). In such random designs, where subjects did not know if the following stimulus would be task-relevant or not, the N_1 - P_2 amplitudes were identical for both types of stimuli.

In contrast to the latter studies, however, some with random designs have shown that the N_1 - P_2 waves are actually augmented for relevant but not for irrelevant stimuli (Schwent and Hillyard, 1975; Picton and Hillyard, 1974). Their results are in accord with

earlier suggestions that the N_1 and the P_2 components are sensitive to the subjects' degree of attention to the stimuli..

Furthermore, numerous studies have found that the P_3 or P_{300} , a late-positive wave at about 300-500 msec in latency, is enhanced while a subject gives attention to relevant stimuli, whereas it is diminished or totally absent in the AEP-curve, if he ignores the same stimuli (i.e. Hillyard et al., 1971; Picton and Hillyard, 1974; Wilkinson and Morlock, 1967). There is as yet no general agreement upon how to interpret such data. Consequently, the P_3 has been associated with a plethora of psychological concepts such as: selective attention (Hillyard et al., 1973), arousal (Karlin, 1970; Näätänen, 1967), stimulus salience (Jenness, 1972), information delivery (Sutton et al., 1967), and decision making (Smith et al. 1970); Rohrbaugh et al., 1974).

In contrast to such findings i.e. the P_3 wave accompanies unpredictable task-relevant stimuli which are actively sought, it has also been shown that P_3 is initiated by unpredictable shifts of task-irrelevant auditory stimuli, for example after instructions to ignore them (Roth, 1973), when subjects were occupied by a manual task (Roth and Kopell, 1973), or reading a text (Ritter et al., 1968). Therefore, these authors suggested an alternative explanation of the P_3 , viz. that it is a cerebral component of the orienting reaction to any infrequent and unpredictable event, even when it is task-irrelevant.

Moreover, the P_3 wave has been obtained during infrequent omissions of an expected task-relevant event (Klinke et al., 1968; Picton et al., 1974; Picton and Hillyard, 1974). Apparently, the P_3 component is not necessarily caused by a stimulus, whereas early AEP-components, for example the N_1 , need a stimulus for their evocation.

According to the literature surveyed here, the N_1 , P_2 and P_3

waves were found to be enhanced, when subjects attended to important stimuli. On the other hand, the same AEP-components were diminished when the subjects' attention was directed elsewhere.

In the present study a random design was employed to analyze and systematize the type of AEP fluctuations found when subjects' degree of attention towards "relevant" tones was altered. Four different experimental conditions were used to affect this distribution of attention: discrimination, rest and two kinds of distraction (physical work and reading). Since the subjects' degree of attention to the relevant tones should be at its maximum under discrimination and exceedingly small in conditions of distraction, the N_1 , P_2 and P_3 waves were supposed to be enhanced when the subjects were discriminating and diminished when they were distracted as compared to those waves for the condition of rest.

In addition to measures of AEP-amplitudes, their corresponding latencies were analyzed for each experimental condition.

M e t h o d

Subjects

Twenty student volunteers with normal hearing, 10 males and 10 females, ages ranging from 18 to 30 years (mean 23 yr), paid at a flat rate, participated in the experiment. They were informed in advance of the importance of being fully rested and in condition for the proper fulfilment of experimental tasks. In a practice session all subjects were trained for the evoked potential procedure.

Stimuli

Synthetic sound bursts of 300 msec duration with a 25 msec rise and 25 msec decline were presented binaurally through earphones (TDH 39, 10 ohm) at 65 dB above threshold sound pressure level of $0.0002 \text{ dynes/cm}^2$. The background noise, measured through earphones, was steady at a level of $20 \pm 1 \text{ dB}$ above threshold. Fif-

ty 104 Hz pure tone bursts constituted relevant stimuli whereas 50 irrelevant stimuli consisted of three successive tones (with frequencies of 396, 503, 598 Hz and durations of 80, 120, 100 msec, respectively) forming a tonic sequence.

The relevant tones were presented at random within the total of 100 stimuli given each condition. Intensity of sound as well as the interstimulus-interval (ISI) were held constant throughout the test - session since these parameters affect amplitudes and latencies of AEP-components (Davis et al., 1966). The interval between two successive stimuli was 3.0 seconds, and the mean ISI between relevant stimuli 6.1. A tape recorder (Revox) administered the random mixture of relevant and irrelevant stimuli via earphones. Pulses on a separate channel of the tape controlled the timing of stimulus presentation and the initiation of DIDAC sampling-epochs. With a time interval of 200 msec these pulses were synchronized with stimulus onset and triggering of the sampling-epoch.

Recording apparatus

Evoked potentials were recorded from chlorided silver/silver disk electrodes affixed to the scalp with bentonite paste and adhesive tape, located at a site mid-way between C_3 and T_3 , at M_1 (reference), and at left forehead (ground). Electrode sites (Int. 10-20 system) were prepared by cleansing with acetone.

When the electrodes were applied and the earphones put in position a sample of ongoing EEG activity from the oscilloscope was studied to control for EEG abnormalities and electrode attachment. Fifteen minutes were allowed for stabilization of electrodes.

The EEG signals were fed via amplifiers (Elema Schönander, Type EMT 12) with low and high frequency cut-off at 0.5 and 15 Hz to one a-c converter channel of a DIDAC-4000 computer with sampling-time set at 1000 msec. The computer sampled the elec-

tric activity during the 200 msec preceding and 800 msec following onset of each relevant stimulus and averaged them all (50) in each condition. Average potentials were written out on a Mingograf recorder for manual analysis. The selection of relevant from irrelevant stimuli to be stocked in the computer was accomplished by the experimenter using a switch. Concurrently, the ongoing EEG activity was checked on an oscilloscope for the occurrence of abnormalities during selection. The equipment was calibrated before, and controlled after, each test session.

ECG-activity was derived from Ag-AgCl disk electrodes; two fixated on the chest and the reference on the left arm. The heart rate impulses were fed into one channel of a Mingograf recorder (EEG 16) for amplifying and registered by an automatic counter which accumulated the heart beats during each condition. Onset of ECG-recording was managed by the experimenter.

Procedure

During testing the subjects were sitting in a comfortable lounge-chair in an acoustically shielded room at constant temperature (+20°C) and illumination (150 Lux). Their behavior throughout the test could be studied from an adjacent recording room via an inspection window. To control for contamination of the EEG record by eye-movement artifacts the subjects were instructed to fixate a small cross on a white screen located 50 cm in front of their eyes throughout the recording session. More specifically, they were instructed to refrain from blinking at, or shortly after, the onset of stimuli. All subjects made a series of voluntary horizontal and vertical eye movements to allow an evaluation of these extracerebral contributions to the AEP. They adjusted their body posture, especially neck-position, so that no muscle activity could be observed in the EEG monitored on an oscilloscope. The subjects were instructed to keep their eyes open, remain silent and refrain from all bodily movements during the test session, and informed about the importance of collaboration in order to obtain artifact-free AEP-re-

cords. Following training in all experimental conditions for 30 minutes, they completed the test session within 45 minutes. There was a 5 minutes' pause between each condition. All subjects participated during day time.

Design

The experimental paradigm entailed steering attention relative to the task-relevant tones. Each subject participated in four conditions of differing task-demands. For condition of rest (1) the instructions were simply to maintain ocular fixation. For physical distraction (2) the subjects were instructed to ignore auditory stimulation completely and to perform a self-paced series of bilateral hand dorsiflexions, something which involved pressing of two identical and elastic rubber balls. A second "ignore-condition", mental distraction (3), required reading a text on "Ego autonomy and psychoanalytic technique" by R. M. Loewenstein (Psychoanal. Quart., 1, 1972). For discrimination (4) the task was to detect the relevant tones and to count mentally how many times two of them occurred in succession.

Conditions were administered in a counterbalanced order, and the effects of fatigue or habituation were checked by presenting a certain condition to 10 subjects during the first half of the session and same condition to another 10 subjects in the second half.

After every session all subjects took part in a structured follow-up interview that checked the effectiveness of instructional and task-demands in directing the individuals' attention to or away from the relevant stimuli.

Analysis

The analysis was based upon averaged EEG traces for the 800 msec following each relevant tone from the four experimental conditions. The components of the AEP were scored by the experimenter on three occasions separated by one month. In

those instances in which estimates on amplitudes and latencies differed their median was accepted.

Six components were measured, with approximative peak latency over all conditions and subjects as follow: (a) a positive component (P_1) with a latency of 25 msec; (b) a negative (N_1) of 90 ditto; (c) a positive (P_2) of 170 ditto; (d) a negative (N_2) of 255 ditto; (e) a positive (P_3) of 305 ditto; and (f) a negative component (N_3) with a latency of 355 ditto.

The amplitudes of the AEP wave complexes P_1-N_1 , N_1-P_2 , P_2-N_2 , N_2-P_3 and P_3-N_3 were scored peak-to-peak.

To estimate an autonomic index of task-involvement during each condition, mean heart rate (HR) in beats per minute was constructed from ECG-data.

In the statistical analyses the Friedman two-way analysis of variance by ranks, the Wilcoxon matched-pairs signed-ranks method and the Mann-Whitney U test were applied.

R e s u l t s

Fig. 1. shows superimposed average wave-forms for two representative subject in all experimental conditions. Subjects seem to differ in relative size of wave-form components, in magnitude and location of differences evinced in the wave-form and in the degree to which these are altered under different conditions. For some components amplitude differences can be observed under different experimental conditions. For discrimination (condition 4) the positive component P_3 seems to be greatest. This component practically disappears under the two conditions of distraction (2 and 3) and sometimes under condition of rest (1). For conditions of distraction, the negatively rated component N_1 becomes smaller.

These visual impressions were confirmed in the following mea-

surement of peak and trough amplitudes for every component. The median and its quartile-deviation were calculated for each component (Table 1).

The median amplitudes for the components: P_1-N_1 , N_1-P_2 , P_2-N_2 , N_2-P_3 and P_3-N_3 seem to be greater in discrimination than in rest and in the two conditions of distraction.

To analyze the effects of experimental conditions the Friedman test was applied as an overall analysis of variance.

This procedure revealed significant differences in amplitude for the components N_1-P_2 ($\chi_r^2=23.12$ $P<0.001$), N_2-P_3 ($\chi_r^2=38.27$ $P<0.001$) and P_3-N_3 ($\chi_r^2=22.58$ $P<0.001$).

Furthermore, to test the origin of these differences statistical analyses with the Wilcoxon method was used for all subjects (one-tail test). The amplitude for the components N_1-P_2 , N_2-P_3 and P_3-N_3 were larger under condition of discrimination compared to rest ($P<0.01$; $P<0.005$ and $P<0.005$ respectively). These amplitudes were also larger for discrimination than for physical distraction ($P<0.005$) and mental distraction ($P<0.005$). Thus, the amplitudes N_1-P_2 , N_2-P_3 and P_3-N_3 were largest for discrimination than corresponding amplitudes for rest and conditions of distraction.

The next step was to analyze the conditions of distraction which were most effective in reducing the amplitudes. Further tests with the Wilcoxon method showed that amplitude N_1-P_2 for rest was larger than for physical distraction ($P<0.025$) and also larger ($P<0.01$) compared to reading (Fig. 2a).

The amplitude N_2-P_3 for rest was significantly larger than for reading ($P<0.005$), but not different from the corresponding amplitude for physical distraction. Furthermore, this amplitude was larger for physical distraction compared to reading ($P<0.005$). See Fig. 2b.

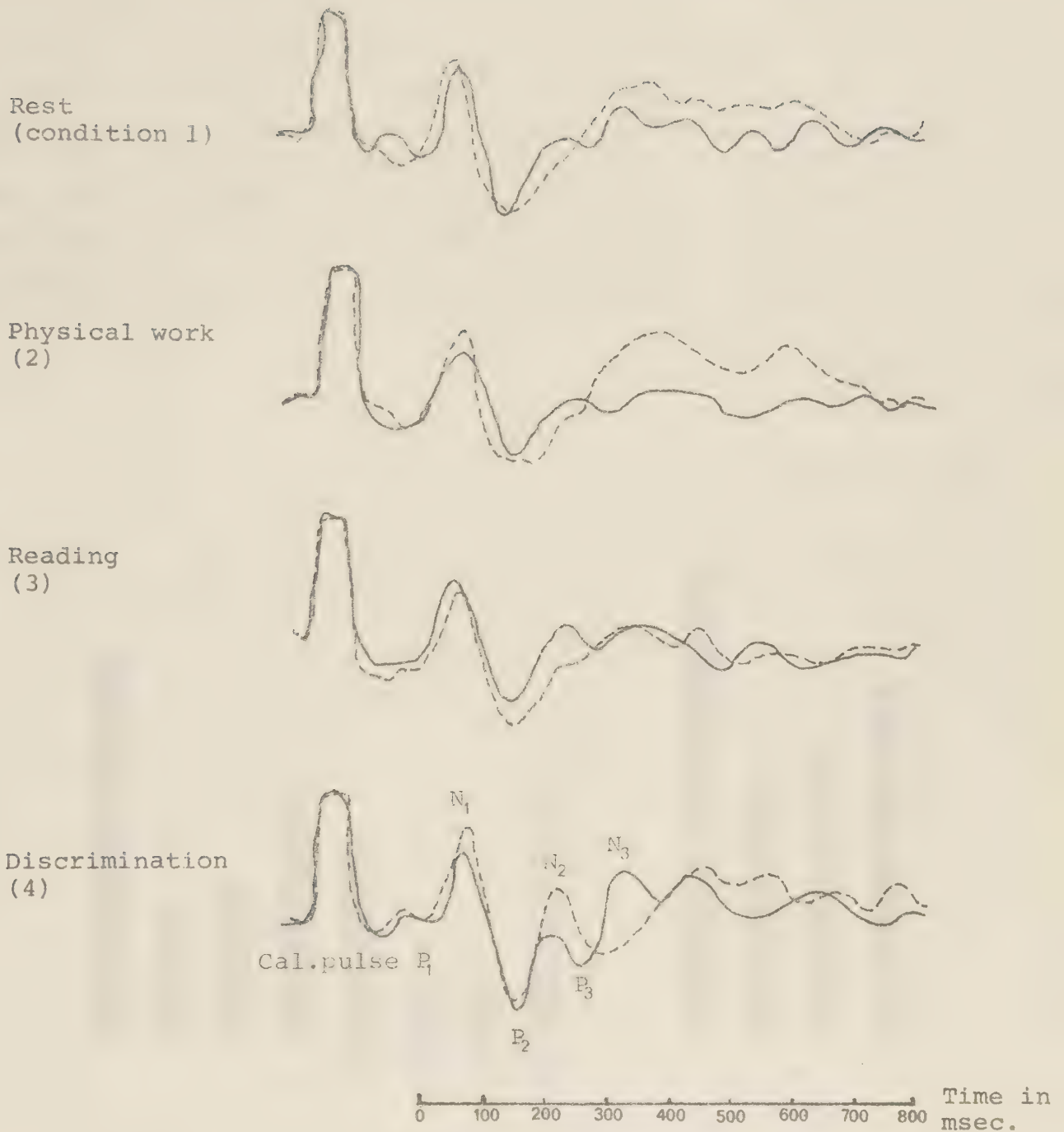


Fig. 1. The curves show the superimposed average wave-forms from the left hemisphere of subjects 1 and 16 (dots and solid line, resp.) obtained under the four conditions. Peaks and troughs are indicated in the curves from condition 4. Negative is up and the calibration pulse, at the beginning of each wave, is $10 \mu V$.

Table 1. Median amplitude and its quartile-deviation ($\pm$) for every successive component of the tone AEP under all conditions.

Condi- tion	$P_1 - N_1$	$N_1 - P_2$	$P_2 - N_2$	$N_2 - P_3$	$P_3 - N_3$
1	4.50 $\pm$.81	6.80 $\pm$ 2.17	4.14 $\pm$ 1.41	.43 $\pm$.16	1.94 $\pm$ 1.26
2	4.55 $\pm$.79	6.31 $\pm$ 1.23	3.17 $\pm$ 1.40	.32 $\pm$.15	1.23 $\pm$.80
3	4.63 $\pm$.69	6.01 $\pm$ 1.64	2.85 $\pm$ 1.50	.34 $\pm$.10	1.02 $\pm$.60
4	6.02 $\pm$ 1.26	7.82 $\pm$ 2.25	3.49 $\pm$ 1.63	1.51 $\pm$.63	3.18 $\pm$ 2.07

Median amplitude
in μV

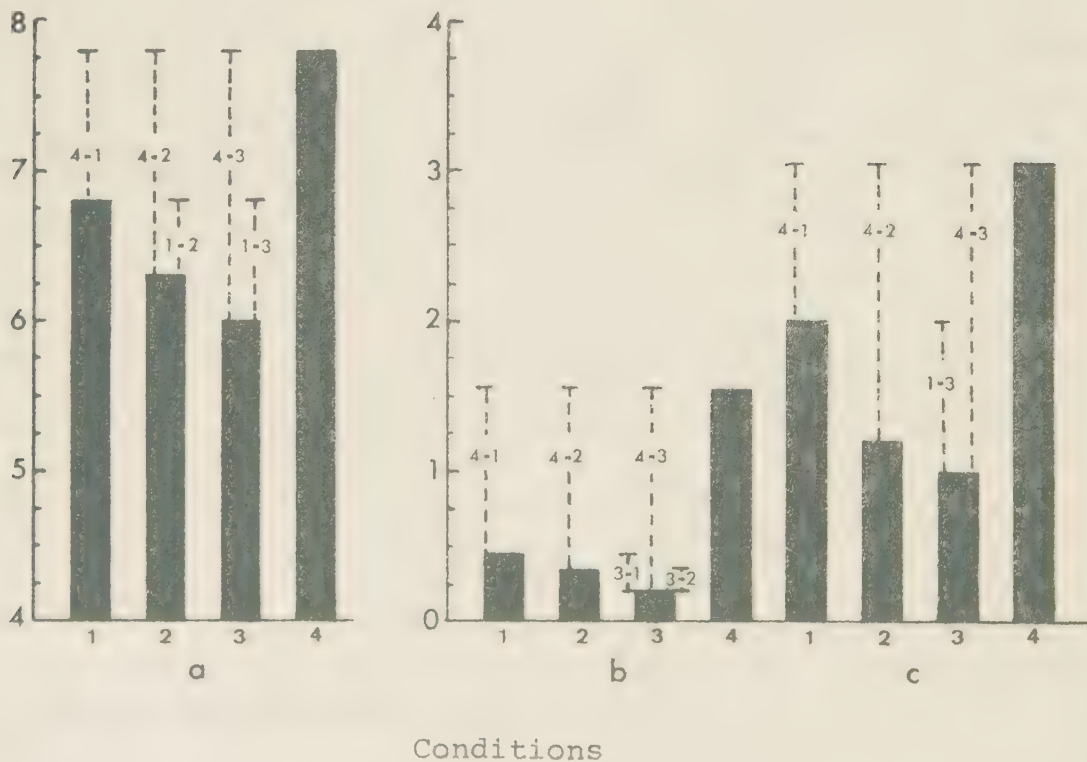


Fig. 2a-c. Significant differences in amplitudes of the AEP-components $N_1 - P_2$ (a), $N_2 - P_3$ (b) and $P_3 - N_3$ (c) between the four experimental conditions, indicated as dotted lines with references ($n_x - n_y$) to compared conditions.

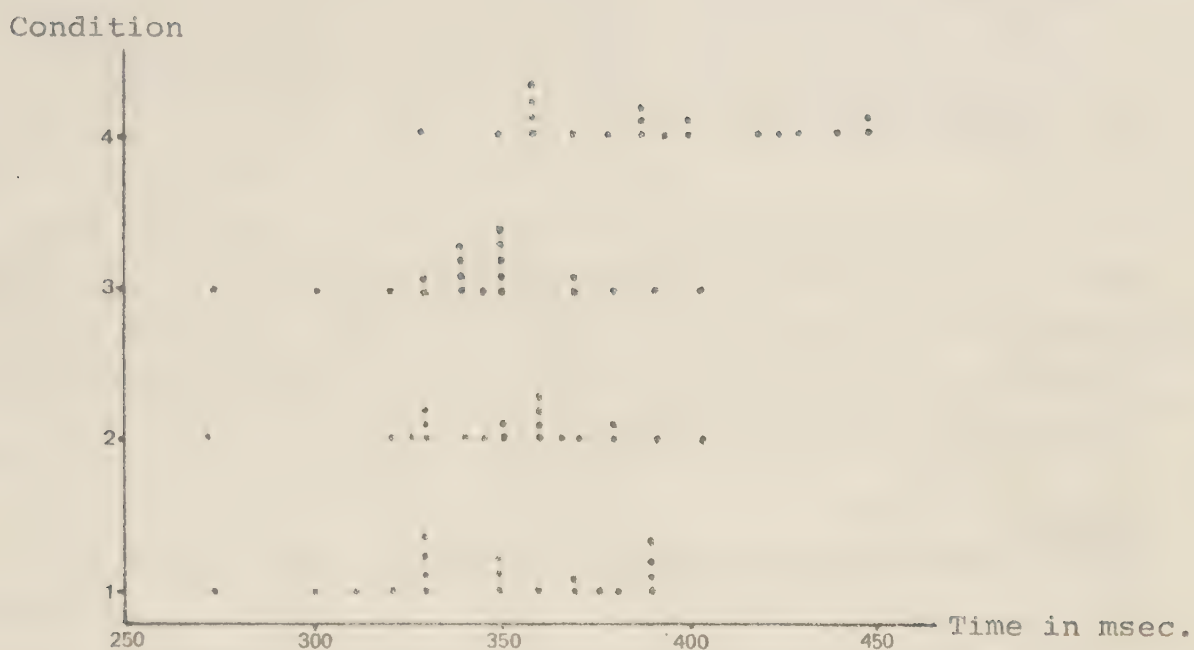


Fig. 3. The dots show the distribution of the N_3 -latencies for all subjects under each condition.

Median latency
in msec.

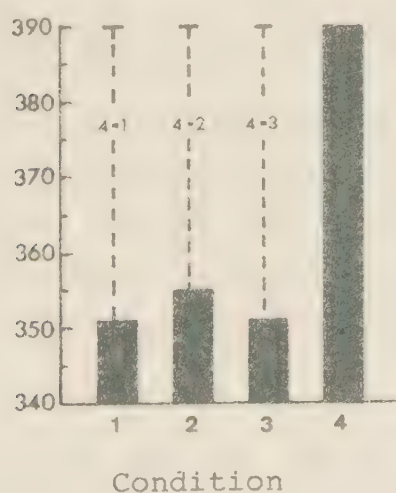


Fig. 4. The bars show peak latency of N_3 derived from average wave-forms of all subjects for different conditions. Significant differences of N_3 -latency between experimental conditions are indicated by dotted lines with reference ($n_x - n_y$) to conditions compared.

There was no difference of P_3-N_3 amplitude between rest and physical distraction. However, the amplitude for rest was larger ($P<0.025$) than for reading (Fig. 2c). No significant differences of the amplitudes in other AEP-components between conditions were revealed.

In sum, the amplitudes of component N_1-P_2 , N_2-P_3 and P_3-N_3 were all augmented under discrimination compared to all other conditions. For mental distraction (reading) the same amplitudes were all reduced compared to rest. Physical distraction only reduced the amplitude N_1-P_2 .

Latency

The Friedman procedure disclosed a significant ($\chi^2=21.42$ $P<0.001$) overall difference of the N_3 latency between experimental conditions. Further Wilcoxon-tests disclosed that this latency was longer for discrimination than for reading ($P<0.005$), physical distraction ($P<0.005$) and rest ($P<0.005$). No other latencies were significantly altered by experimental conditions (Figs. 3 and 4).

Summary of changes in amplitudes and latencies between the four different conditions

The amplitudes N_1-P_2 , N_2-P_3 and P_3-N_3 were larger and the N_3 latency longer under discrimination compared to rest, physical and mental distraction. In mental distraction (reading) these amplitudes were all reduced compared to resting, but with no alterations in latencies. Physical distraction only reduced the N_1-P_2 amplitude.

Differences in amplitude and latency related to habituation

Habituation or fatigue may alter the amplitude and latency of AEP components during the session lasting 45 minutes. To control for sequence effects the order of condition-presentation within each experimental set was counterbalanced. Statistical testing was performed on amplitudes and latencies of two groups of sub-

jects being exposed to a particular condition either in the first or second half-session. Thus, a comparison was made between 10 subjects exposed to a given condition in the first half of the session, and 10 subjects receiving the same condition in the second half (Table 2).

Application of the Mann-Whitney U test between groups for all conditions showed no significant difference ($P > 0.05$). For example, when discrimination was introduced in the first and the second half-session there were no significant differences in N_3 latency and amplitudes of N_1-P_2 , N_2-P_3 and P_3-N_3 . Thus habituation or fatigue played no significant role in the alternations of latencies and amplitudes within the framework of the present experiment.

Table 2. Alternations in median amplitude and latency of AEP components in relation to order of presentation.

Condition	Order of presentation in experimental half-session	Median amplitude and quartile-deviation in μV for components:			Median latency and quartile-deviation in msec for N_3
		N_1-P_2	N_2-P_3	P_3-N_3	
1	First	6.00 $\pm$ 1.70	.39 $\pm$.22	1.93 $\pm$ 1.23	360 $\pm$ 26
	Second	7.36 $\pm$ 1.71	.44 $\pm$.15	1.64 $\pm$ 1.09	350 $\pm$ 23
2	First	6.32 $\pm$ 1.29	.40 $\pm$.29	1.15 $\pm$.44	345 $\pm$ 19
	Second	6.31 $\pm$ 1.03	.29 $\pm$.15	1.50 $\pm$ 1.33	362 $\pm$ 17
3	First	6.14 $\pm$ 1.85	.30 $\pm$.15	.90 $\pm$.65	342 $\pm$ 13
	Second	5.84 $\pm$ 1.32	.21 $\pm$.10	1.13 $\pm$.55	350 $\pm$ 15
4	First	7.44 $\pm$ 2.92	1.83 $\pm$.65	3.50 $\pm$ 2.17	385 $\pm$ 20
	Second	8.33 $\pm$ 1.98	1.21 $\pm$.30	2.64 $\pm$.87	397 $\pm$ 33

Task-involvement

The mean heart rate (HR), used here as an index of task-involvement, was 63, 72, 68 and 66 beats per minute under the conditions 1-4. Significant overall differences of HR between experimental conditions were found by the Friedman-test ($\chi^2_r = 30.48$ $P < 0.001$).

Further Wilcoxon-analyses (Fig. 5) showed that the HR for reading was higher than for rest ($P < 0.005$). The HR was also significantly heightened under physical distraction ($P < 0.005$) as compared to rest. This was not the case for discrimination. Under physical distraction the HR was higher than for reading ($P < 0.005$) and discrimination ($P < 0.005$).

In sum, the HR was higher for the two types of distraction (physical work and reading) than for rest. However, the HR was not significantly heightened for discrimination compared to rest.

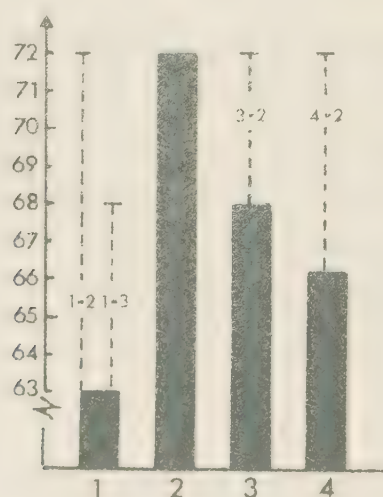


Fig. 5. The dotted lines with reference ($n_x - n_y$) to compared conditions show significant differences in mean heart rate (HR) for different conditions.

D i s c u s s i o n

The foregoing results clearly indicate that both early and late waves of the AEPs fluctuated differentially and in a systematic manner under each condition.

Psychological correlates of the N_1 and P_2 waves.

It has been well established that the auditory evoked potential is composed of about 15 components (Picton et al., 1974). However, the extent to which they indicate separate processes is as yet unknown. In the present study, therefore, some of the waves may have been both temporally and spatially overlapping.

There is general agreement that the two most prominent as well as separate AEP components are the N_1 (80-120 msec in latency) and the P_2 (160-200). Findings have been reported showing that the amplitudes of the early AEPs are dependent on the duration of the interstimulus interval (Öhman and Lader, 1972) and variations in stimulus-intensity (Davis et al., 1966). None of these factors, as such, influenced the present results, since the ISI was identical for all conditions and the intensity of relevant tones was constant at 65 dB throughout the experiment.

On the other hand, Picton and Hillyard (1974) have found that the amplitudes of N_1 (90 msec in latency) and P_2 (170 ditto) are significantly increased when subjects are occupied in detecting relevant click-stimuli as compared to those amplitudes while reading a text. Their finding is in accord with the present data, showing that the N_1 - P_2 amplitude is enhanced under discrimination (condition 4) and reduced for conditions of distraction (2 and 3) relative to rest (1).

In the present random design, enhanced N_1 - P_2 amplitudes for relevant tones were obtained when subjects were discriminating, but not when they were simultaneously engaged in other experimental tasks. This result is in line with findings from other random studies (Hillyard et al., 1973; Picton and Hillyard, 1974;

Schwent and Hillyard, 1975) indicating that the N_1 - P_2 amplitude is influenced by attentive factors, whereas it was not in accord with results supportive to interpretations in terms of, e.g. differential preparatory arousal (Näätänen, 1967, exp 2; Smith et al., 1970; Wilkinson and Lee, 1972). Since the AEPs to relevant tones in the present experiment could not be separately averaged in the same run, the tones were delivered under 4 conditions with different task-requirements and instructions. It is possible, therefore, that the early AEP-fluctuations found here were in fact reflecting differential states of the subjects, since subjects' degree of attention towards relevant tones and hence evaluation of the same stimuli were changed across experimental conditions. It seems reasonable to suppose that those states might differentially affect the processing of the tones delivered.

Psychological correlates of the P_3 wave.

At present there is indeed much uncertainty as to how many types of the long latency positive wave - variously designated P_3 , $P300$, late positive component or association cortex potential - which can be differentiated with regard to their topographic distribution, brain generators and distinctive psychological correlates. Recent findings indicate that the P_3 may represent a family of P_3 waves (Papakostopoulos and Crow, 1975; Squires et al., 1975).

This possibility of several and perhaps separate P_3 waves demonstrates the inconvenience of the traditional interpretations of the P_3 in terms of single psychological constructs such as arousal, selective attention etc. In addition several investigators have reported results which are difficult to interpret in terms of such unitary views of P_3 . For example, Picton and Hillyard (1974), Ritter et al. (1968) and Roth (1973) have all found that the P_3 can be elicited both by relevant stimuli presented in attentive conditions requiring decision making, and by seemingly irrelevant stimuli under conditions of "non-attention". Rather, these findings indicate that the P_3 wave has no single psychological concomitant, and hence may represent a complex phenomenon.

Two different explanations of the P_3 have been most influential. According to the first and complex one the P_3 may be, just as are the N_1 and P_2 components, affected by a tonic state of preparedness developing prior to the expected relevant stimuli (Näätänen, 1967; Karlin, 1970). For example, Näätänen (ibid.) argues that the P_3 -production is dependent upon the operation of preparatory nonspecific tonic arousal prior to significant stimuli. In this experiment, however, relevant and irrelevant tones were randomly delivered for each condition. Consequently, there were few opportunities for the subjects while, e.g. discriminating (condition 4) to be solely prepared for relevant tones. The augmentation of P_3 amplitudes under this condition as compared to those for rest (1) could, therefore, not have been effects of just heightened tonic arousal. Apparently, this result is in line with findings from several random experiments, where differentially enhanced P_3 waves were only obtained for relevant stimuli (Donchin et al., 1973; Hillyard et al., 1971; Hillyard et al., 1973; Ritter et al., 1968; Wikinson and Lee, 1972).

However, the present design did not preclude the development of certain states of the subject differing for each condition, especially at the moments of delivering the relevant tones under the attentive (4) and non-attentive (1-3) conditions. Presumably, the augmented P_3 waves for discrimination (4) relative to those for conditions of distraction (2 and 3) and rest (1), as well as the diminished P_3 s under 2 and 3 as compared to 4 and 1, could be associated with such differential states.

The second and unitary accounts for P_3 assume that it is exclusively associated with post-stimulus events, thus with phasic processes arising after the presentation of relevant stimuli. Frequently advanced correlates in this context are the simple constructs such as selective attention, orienting reaction and decision making.

The difference between the complex view of P_3 proposed here and

the traditional accounts is that the differential states represent, according to the former view both pre-stimulus and post-stimulus psychological processes. Hence, they occur prior to the moments of delivering stimuli as well as during the processing of the same stimuli, and may in this way influence to varying degrees the development of the P_3 or the family of P_3 waves.

In line with this reasoning several results (see Tueting and Sutton, 1973) indicate that the P_3 wave may be dependent upon pre-stimulus effects reflected by, for example, the contingent negative variation (CNV). This slow negative baseline shift, however, was neither designed for nor sampled in the present study. Besides, clear CNVs have been obtained even under unpredictable settings where the probability that the next stimulus will be task-relevant was 0.50 (see Näätänen, 1975, p 258). Accordingly, CNVs could have occurred, and most likely under the attentive condition, in this random experiment as well.

Since the relevant tones had long interstimulus intervals (with a mean of 6.1 seconds), the subjects' opportunity for strategic thinking during the successive delivering of the tones within a run was facilitated. This means that despite random presentation of tones the subjects could have used some strategies in order to anticipate the occurrence of the next tone, particularly so under discrimination, and probably even in the condition of rest. It is therefore possible that the probabilities of the immediate presentation of a relevant tone were altered for each condition, something which invoked the use of different types of strategies. Consequently, the differential states mentioned previously and here specified to involve different strategies may have been associated by CNVs preceding the relevant tones. Hence, the CNVs' positive return to baseline could have partly contributed to the differential P_3 s found in this study. A reasonable assumption of the complex view of P_3 is therefore that pre-stimulus psychological processes - such as strategies perhaps associated with CNVs, and post-stimulus processes associated with AEPs which are dis-

cussed later -, may all contribute to the development of the P_3 . This supposition is equivalent to the one advanced recently by Donchin et al. (1975), stating that the CNV-resolution could contribute to the P_3 amplitude in settings where the relevant stimuli are somehow anticipated; but does not imply that the P_3 is largely and perhaps exclusively composed of CNV-resolution (Näätänen, 1975; Wilkinson and Ashby, 1974). The present hypothesis is also consistent with the possibility that the CNV-resolution and the P_3 may represent two independent brain-phenomena, differing in scalp topography, brain generators and perhaps even psychological concomitants, and which operate as two additive sources of positivity.

The process view of AEPs.

The complex account for the P_3 advanced here also has implications for the interpretation of evoked potentials (EPs) in general. The minor interest given to basic issues - some methodological difficulties inherent in the EP-technique and some conceptual ones - has definitely contributed to the great variety of accounts for seemingly paradoxal results in the field of EP-research.

A most important contribution which could partly explain this excess of simple psychological constructs is a general lack of knowledge about the subject's strategy in the experiment. According to the traditional hypothesis the subject uses the type of strategy determined a priori by instructions. He is furthermore assumed to use the same strategy to the same degree and towards every task-relevant stimulus throughout the experimental condition.

Obviously, this assumption about the subject's strategy, which is seldom explicitly stated, is a dangerous oversimplification of what he really is doing during the test. In this respect a complex process view of AEPs may be more appropriate. This view implies that the AEP is reflecting an average of repeated pro-

cesses of discrimination for both the relevant and irrelevant stimuli which are delivered. Moreover, the subject-determined strategy - not necessarily conscious reasoning - is flexible under a run and will involve the proper type of decisions during the discrimination of stimuli in detection tasks. Furthermore, it is proposed that at least three types of decisions may differentially affect the process of stimulus discrimination. They set into operation in order to answer the following "questions"; (1) is something happening?, (2) what is it?, and (3) is it task-relevant?

Applied to the present study, particularly the conditions of discrimination and rest, the subjects could use different types of decisions owing to these factors:

(A) The subjects' momentary strategy i.e. task-involvement. It is dependent upon the degree of task-experience and the effectiveness of instructions. To control the effectiveness of instructions in changing experienced subjects' degree of attention towards the relevant tones, follow-up interviews were given to all subjects and for all conditions. They revealed that one subject under physical distraction (2) and three in mental distraction (3) had sometimes listened to the tones. Thus, almost all subjects ignored the tones delivered under conditions of distraction. Furthermore, all subjects were totally pre-occupied while discriminating (4) the tones, but listened less often to them when resting (1).

The autonomic index of the subject's task-involvement used - mean heart rate - was found to be significantly greater for all conditions of distraction as compared to the condition of rest.

The results indicate that the subjects' momentary strategy under each condition was the one intended by the experimenter.

(B) The degree of predictability of relevant and irrelevant stimuli from the subjects' point of view. This factor involves two basic issues:

(B:1) The relevance of "relevant" stimuli. In most AEP-studies "task-relevant" or "attended" stimuli have referred to the specific stimuli which the subject was instructed to detect or otherwise respond to. All other stimuli have been designated as "task-irrelevant" or "unattended". The stimuli thus are defined from the experimenter's point of view but not as the subject may have interpreted them. Clearly, the use of such vague definitions constitutes a priori assumptions about the problem to be investigated and has recently been questioned by a few researchers (Näätänen, 1975; Wilkinson and Ashby, 1974).

In the process view, however, the subject's evaluation of each stimuli delivered is emphasized. It moreover implies that all stimuli presented are undiscriminated prior to the "what is it"-phase is reached. The stimuli will not be classified before this moment.

(B:2) The meaning of "regular" and "irregular" presentation of stimuli. There are no attempts so far to analyze the real meaning of the terms "predictability" and "unpredictability". In unpredictable settings for example the assumed unpredictability is believed to be guaranteed by using irregular presentation of stimuli, at best in random series. Consequently, the intricate issue of how the subject himself may experience the irregularity of stimuli has been by-passed.

It is emphasized here that by using irregular presentation of stimuli with long ISIs (duration of 1 second and more) there may nevertheless exist some bases from which a motivated subject can anticipate what the nextcoming stimulus will be. This may be so because the momentary strategy -determined by e.g. instructions- is continuously adjusted during the delivering of tones. Specifically, whenever the subject detects a pattern in the presenta-

tion of tones his strategy is changed, on the basis of his experience of each tone. His experience of regularity or irregularity is therefore associated with the operation of different and flexible within-condition strategies which also may be quite different from the momentary strategies set by the experimenter.

In principle, the development of such flexible strategies is possible, but is very difficult under conditions where short ISIs (shorter than 1 sec) are used in order to force subjects to ignore irrelevant stimuli (e.g. Wilkinson and Lee, 1972), and very unlikely for extremely brief ISIs (Hillyard et al., 1973).

(C) The degree of habituation. Habituation is another potential factor which may influence the subject's strategy. The possibility of habituation between conditions was effectively controlled here by counterbalancing their presentation-order. Furthermore, statistical testing showed no differences of amplitudes and latencies for a given condition presented in the first and the second half-session of the present experiment. Consequently, the significant changes of amplitudes (N_1-P_2 , N_2-P_3 and P_3-N_3) and latency (N_3) were not effects of between-condition habituation or fatigue.

In addition, since there were no reports of fatigue in the follow-up interviews, the subjects' momentary strategies were most likely unaltered by sequence-effects.

However, habituation within a condition - something which is closely related to the issue of regularity, might have occurred here, since the relevant tones were delivered fifty times within a run. If so, the habituation-rate of individual evoked potentials was very slow because the mean ISI of relevant tones was 6.1 sec in this experiment. In addition, the subjects' evaluation of stimulus-relevance was changed for each condition. In discrimination for example the fifty tones were evaluated as task-relevant

and important, whereas they were evaluated as unimportant in the other conditions. This evaluation of tones, which determined the appropriate type of momentary strategy to use, could reduce the speed of within-condition habituation. This effect might contribute to the large amplitudes observed for discrimination. Hence, only the use of individual-EP technique reveals the existence of this type of habituation and how the AEPs are affected.

The issue of habituation also has implications for the interpretation of the P_3 wave. An explanation in terms of the orienting reaction seems inappropriate for the present findings since the subjects were all trained and thus habituated to the tones used. If indeed ORs were initiated these contributions of individual P_3 s were too small to create significant differences between the conditions in the average amplitude of P_3 .

In sum, the process view implies that factors A - C influence the proper type of momentary strategy to use. This is furthermore continuously adjusted due to experience acquired under a given condition and influences the type of decisions required as well as their timing within the process of discriminating each stimulus. It is proposed that decisions are involved during three phases of stimulus-discrimination, namely those of (1) is something happening, (2) what is it, and (3) is it task-relevant.

This view implies for the present condition of discrimination that all decisions were activated, since the subject had to decide if the stimulus delivered was relevant or not. The tones were all familiar in this study. A reasonable assumption therefore is that the classification-phase was reached sooner here than if the tones had been infrequent and the subjects unfamiliar with them.

On the other hand when subjects were simultaneously occupied by distractional tasks such as reading a text, their strategies

were presumably quite different. Under these circumstances, when attention was given to other events subjects may have reached the decision that something was heard and that it was a tone, whereas they seldom concluded that the tone was, for instance, relevant.

Consequently, it is argued here that the AEP-amplitudes, especially those for the conditions of discrimination and rest, reflected: (1) pre-stimulus processes such as momentary and flexible strategies, and (2) post-stimulus processes such as the decisions mentioned previously.

It could be hypothesized that the early and late AEPs are associated with different phases of stimulus discrimination. Since the P_3 wave has a relatively long latency it may reflect the decisions operative at the last phase ("is it task-relevant"). Moreover, it is even likely that the P_3 may constitute a whole family of P_3 s. If so, each sub-wave within such a family may be associated with different psychological processes activated when subjects discriminate a stimulus. This relation between P_3 and decision making concerning suprathreshold stimuli is supported by data from recent studies using ambiguous threshold-level auditory signals (i.e. Squires et al., 1975). These authors found that the P_3 for signal - present decisions was significantly correlated with the subjects' certainty about heard a signal - whether or not it was actually present. The P_3 was also associated with signal-absent decisions when the stimulus-absence was clearly recognizable and relatively improbable.

Among the AEPs, the N_1 - P_2 waves are most sensitive to non-psychological factors such as stimulus-intensity. Conversely, the P_3 is unrelated to those factors and is even found to be elicited in cases when no stimulus is present. The P_3 therefore seems to hold most promise of psychological import.

For definitive tests of the process-explanation of AEPs the

single-EP technique and simultaneous measurements of the topographic distribution of AEPs as well as of CNVs should be applied in model-situations. In such studies the different strategies - momentary and flexible - are explicitly stated in the instructions to the subjects and are designed for by an appropriate order of delivering stimuli. Hence, it could be observed in what manner significant changes of AEPs are correlated with the psychological processes activated pre- and post-stimulus.

Latency fluctuation of the AEPs.

Some researchers have found that experimental manipulation of attention variables does not affect the latencies of AEPs occurring within an interval of 300 msec after stimulus-onset (i. e. Picton and Hillyard, 1974). This finding is supported by the present data which show no changes in peak latencies prior to the N_3 latency (355 msec).

Conversely, the observation of stable P_3 latency is inconsistent with evidence which shows that it can vary considerably between physically identical stimuli. For example, the P_3 latency was reported to be about 100 msec longer under vigilance than under simple reaction time, and also longer for a harder as compared to an easier task of discrimination in a vigilance-condition (Ritter et al., 1972).

The present evidence of stable latencies for the N_1 , P_1 , N_2 and P_2 waves is in accord with the results from both studies mentioned previously, indicating that these early latencies are likely to be unaffected by attentional factors.

On the other hand, here, only the N_3 latency among the late latencies of the AEPs was changed for each experimental condition. It was longer under discrimination than for other conditions. This fact complements the changes in P_3 latency found by Ritter et al. (ibid.), since discriminating in this experiment in all probability required different decisions during the discrimina-

tion of stimuli than did other conditions.

Latency variability of the individual evoked potentials.

To equate changes in AEP amplitudes with variations in responsiveness at either the neurophysiological or psychological level is premature since definitive evidence for such relationships are as yet lacking. It is conceivable therefore that AEP amplitudes neither indicate the amount of neural activity nor the amount of processing stimulus. Before any definitive conclusions regarding this fundamental issue can be drawn, the possible effects of latency variability in individual EPs on the average evoked potentials have to be studied by using individual-EP techniques.

As a consequence of the inherent limitation of the traditional AEP-technique it is not possible to firmly state that the individual latencies of, for example, the N_3 wave - obtained here from the fifty individual sampling points in a run - were stable in each condition.

If latency variability in individual EPs really occurred in this study the observed changes in amplitudes of AEPs across conditions could be interpreted: Owing to an increased dispersion of individual latencies, for example those of the average N_3 latency, when subjects were reading a text relative to the same latencies under the condition of rest, their corresponding average N_3 amplitude under reading might have been diminished. In general, it is possible that the reduced average amplitudes for the conditions of distraction, were the effects of the relatively increased variability of their corresponding individual latencies.

Specifically, since latencies of the AEPs are generally considered to reflect different moments during the processing of stimulus presented, the greater dispersion of individual latencies for reading may indicate a more differentiated time-

interlinked activity. This means that the individual amplitudes of e.g. the N_3 wave can in fact be identical throughout this condition, whereas the corresponding individual latencies may fluctuate. Hence, if their dispersion were greater for reading than for the condition of rest, the individual N_3 amplitudes under reading would be unaltered in magnitude despite the observed reductions in the average N_3 amplitude.

In addition, the increase of average P_3-N_3 amplitude for the condition of discrimination as compared to the one for rest may not reflect an augmentation of any type of neural activity or processing of relevant tones, but rather a relatively smaller dispersion of individual N_3 latencies under discrimination. The long average N_3 latency in this condition could, then, simply indicate a greater number of longer individual N_3 latencies as compared to other conditions in which those latencies also fluctuated or perhaps were stable.

Some or all of the significant augmentations in AEPs for attentive (discrimination) as compared to non-attentive conditions (i.e. reading) might therefore indicate the activity of different psychological processes at different moments during the discrimination of relevant stimuli.

Applied in terms of the process view of AEPs the different phases involved during the discrimination of each relevant tone were reached at different moments for the attentive and non-attentive conditions. These moments are indicated by the dispersion of different individual amplitudes. Since different decisions are associated with each phase of stimulus-discrimination the former might be initiated at different rates under the conditions mentioned.

It has been exemplified here in what manner the variability of individual EPs could affect the AEPs. If such effects are found to be influential, for example, by using individual-EP tech-

niques, then, the process view of AEPs advanced here would seem to be appropriate for explaining these findings.

Summary and conclusions

AEPs have been shown to fluctuate in a systematic manner with the degree of attention distributed to the relevant tones. In the condition of discrimination when subjects were preoccupied with processing these tones, the amplitudes of N_1-P_2 , N_2-P_3 and P_3-N_3 were all enhanced, whereas the same amplitudes were attenuated when subjects were engaged in distractional tasks. All latencies of the AEPs were stable except the N_3 which was prolonged under discrimination as compared to the other experimental conditions.

Different interpretations of the P_3 emphasized previously in the literature is compared with a complex view introduced in the present study. It has considerable implications for the interpretation of AEPs as well as for EPs in general. This complex process view is elucidated from basic methodological and conceptual aspects such as (1) momentary strategy of the subject, (2) predictability of relevant and irrelevant stimuli, and (3) habituation.

According to this view the optional strategy of the subject under the condition of discrimination and even rest was continuously adjusted by experience acquired during the repetitive delivering of tones, something which influenced the type of decisions activated during each phase of stimulus discrimination. It is proposed that decisions occurred during all phases mentioned previously. Under the conditions of distraction, however, the subject's strategy was seldom or never adjusted and the decisions were mostly involved before the classification of stimuli as being relevant or irrelevant. Hence, it is argued that the AEPs, but the P_3 in particular since it seems most sensitive to psychological factors, were effects of pre- and post-stimulus processes such as strategies and decisions, respectively.

Finally, the possible effects of latency variability in individual EPs on the development of AEPs are discussed. Methods of studying such effects and crucial tests of the process view are also suggested.

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*Selective Attention and Auditory Evoked
Potentials in Man*

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A b s t r a c t . - Administered binaurally 50 randomly dispersed /ba/-stimuli to 20 subjects aged 18 to 30 years under five conditions of differing attention: discrimination, rest and three kinds of distraction. Average evoked potentials (AEPs) to speech stimuli were augmented under discrimination and were in general diminished under differing conditions of distraction as compared to rest. The N_1 - P_2 , N_2 - P_3 and P_3 - N_3 amplitudes fluctuated systematically across conditions and in the same manner as in a previous experiment employing pure tones. These differential alterations in wave-amplitudes, but especially in the P_3 amplitude, were effects of strategies and decisions according to a process view of AEPs presented earlier. The generality of these AEPs changes is discussed and a tentative process approach which seems to be appropriate to studying human selective attention is outlined.

In a previous investigation (Hedman, 1975) it was shown that the average evoked potentials (AEPs) to tones fluctuated systematically with altered attention to the relevant tones. The N_1 - P_2 and P_3 components were enhanced under a condition of discrimination and reduced under distraction as compared to a condition of rest.

One objective of the present investigation was to determine if these findings can be reproduced using a supplementary distractive task which requires complex memorization of visually delivered digits. Since subjects reported in pilot studies that this task effectively diverted their attention away from simultaneously given stimuli, it was expected that the AEPs mentioned previously will diminish most under this additional condition of memorizing as compared to other experimental conditions.

Another aim was to find out if the above results could be generalized as being valid in more naturalistic settings. Therefore, speech stimuli were used instead of pure tones. Moreover, a study by Lawson (1966) has shown that irrelevant verbal stimuli are ignored to a greater extent than irrelevant tones when both are presented in the rejecting ear during simultaneous shadowing of different verbal stimuli given in the attending ear. Applied to the present context it could be predicted, therefore, that the AEPs are more diminished when using verbal (speech) stimuli

than are the same AEPs for tones under distractional conditions where subjects' attention is directed away from the relevant stimuli.

The reason for the last objective was a preliminary consideration of the nature of early AEPs occurring before the N_1 wave; specially as to whether these intensity-dependent components of the AEP fluctuate across the five different conditions as used here.

In 1967 Treisman and Geffen reported that when a subject is instructed to repeat (shadow) speech passages delivered in one ear, he will seldom hear verbal stimuli presented in the other non-attending ear. They postulated the hypothesis that attenuation of non-attended stimuli may reflect a decrease in the sensitivity of the irrelevant sensory "channel".

Various studies on AEPs have shown that the more intense stimuli result in enhanced AEPs generated before the N_1 - P_2 waves (e.g. Davis et al., 1966). It has therefore been assumed from Treisman's peripheral attenuation hypothesis that when attention is directed away from a certain stimulus these early AEPs may be diminished (Picton and Hillyard, 1974; Smith et al., 1970). These researchers, however, found no alternations in early intensity-dependent AEPs across attended and non-attended conditions.

Their results and the consistently reported enhancement of the N_1 wave (90 milliseconds in latency), the P_2 (170 msec) and the P_3 wave (300-500 msec) when the subjects' attention is directed to auditory stimuli may motivate an alternative view of selective attention.

From the process view of AEPs as advanced recently by Hedman (1975), it could be deduced that attention factors influence the discrimination of relevant and irrelevant speech stimuli re-

presented at the cortical level of the central nervous system. If this hypothesis, which is one variant of the centralistic accounts of stimulus selection (see Erdelyi, 1974), is true, then the very early activity during the process of discriminating speech stimuli is unaltered. This might be indicated by stable early AEPs occurring prior to the N_1 wave.

Method

Subjects

Twenty adults with normal hearing, aged 18-30 years, served as paid subjects. All of them had previous experience with EEG recordings.

Stimuli

Synthetic speech stimuli of 300 msec duration, 104 Hz fundamental frequency, with a 25 msec rise and fall time and an intensity of 65 dB SPL were used. Background noise was homogenous at a level of 20 ± 1 dB. A total of 100 consonant-vowel syllables, 50 /ba/ stimuli and 50 /da/ stimuli were presented in each experimental condition. The /ba/ stimuli constituted relevant stimuli and were administered randomly with a mean interstimulus interval (ISI) of 6.2 sec. The interval between two successive stimulus presentations was 3.0 sec. A Revox tape recorder delivered the randomized stimuli through earphones (TDH 39, 10 ohm). The triggering of stimulus onset as well as computer sampling epoch was controlled by synchronized square wave pulses on a separate channel of the tape. The pulse elicited the sampling epoch immediately, and after 200 msec the stimulus onset.

Recording apparatus

Electrical activity was recorded from Ag/AgCl disk electrodes located, according to the International 10-20 system, at a site midway between C_3 and T_3 , at M, (reference, and at left forehead (ground). The stabilization period was 15 minutes and during this time control for EEG abnormalities was performed by scanning the activity on an oscilloscope.

The EEG was amplified with frequency filter setting at 0.5 and 15 Hz, and entered the A-C converter channel of a DIDAC-400 computer for signal averaging. The sampling epoch was 1000 msec:200 d:o preceding and 800 d:o following the onset of relevant stimulus. Only relevant stimuli were stocked by the computer, but the selection of these signals was managed by the experimenter using a switch. The average potentials were registered on a Mingograf recorder for later manual analysis. During AEP recording, EEG activity was followed on an oscilloscope in order to observe and reject signals associated with EEG abnormalities. This happened on one occasion after which the trail was stopped and reiterated. Calibration of equipment was performed before and after every session.

The ECG activity was recorded from Ag-AgCl disk electrodes, two positioned on the chest and one reference electrode on left arm, and led into an EEG apparatus (Elema Schönander, EEG 16) for amplifying. The impulses were finally registered by a counter which accumulated heart beats under each experimental condition. The triggering of the ECG equipment was controlled by the experimenter.

Procedure and design

The subject was seated in a comfortable reclining lounge-chair with neck support in a sound-attenuated electrically shielded room of constant temperature (+20°C) and illuminance (150 Lux), and facing a small fixation-point in the center of a white screen at a distance of 50 cm. He was asked to keep his eyes open and avoid blinking, and utterance as well as body movements during and immediately after presentation of auditory stimuli. In a practice session lasting 35 minutes the subject was trained for these instructions and differing demands of experimental conditions. The following testing session lasted 50 minutes, interrupted by intervals of 5 minutes after each experimental condition. The subject took part in a 5 minutes follow-up interview after the testing session.

The individual's attention to the relevant stimulus was altered by the fulfilment of various task requirements. Under condition of rest (1) they were only asked to look at the fixation-point throughout the experiment. For three types of distraction they were told to ignore the auditory stimulation when simultaneously executing the tasks as follows: (a) squeezing of two elastic rubber balls, physical distraction, (2); (b) analyzing a theoretical text on "Ego autonomy and psychoanalytic technique" (by R. M. Loewenstein. The Psychoanalytic Quarterly, 1, 1972), a condition termed mental distraction (3); (c) in another test for condition of mental distraction (5) the subjects were instructed to memorize a list of 48 digits in a correct order. Under a condition of attention termed discrimination (4) they had to detect and mentally count the number of times two relevant stimuli occurred in succession.

Each subject participated in all conditions presented in a counter-balanced order. To study effects of habituation and fatigue on the AEPs, half of the subjects took part in a given condition presented in the first half of the testing session, whereas the other group of ten subjects carried out the same condition during the second half.

Analysis

The 800 msec following onset of relevant stimuli were analyzed in the AEP curves. Their components were scored three times with an interval of one month. Median amplitude and latency measurements were used if they differed. Six AEP components were fairly easily recognized with approximative peak latencies over all subjects and conditions as follows: (a) component P_1 at 30 msec, (b) N_1 at 100 d:o, (c) P_2 at 180 d:o, (d) N_2 at 265 d:o, (e) P_3 at 290 d:o, and (f) component N_3 at 355 d:o after onset of relevant stimulus. The amplitudes were measured peak-to-peak.

As an index of the subjects' task-involvement under a given condition the mean heart rate (HR) in number of beats per minute was used.

The following non-parametric tests were used in the statistical analyses of amplitude and latency data; Friedman two-way analysis of variance by ranks, Wilcoxon matched-pairs signed-ranks method, and Mann-Whitney U test.

R e s u l t s

Fig. 1. shows AEP for two representative subjects under all conditions. Subjects seem to differ in the relative size of their respective wave-form components, in the magnitude and location of differences in the wave-form and in the degree to which these alter between conditions. The figure suggests certain generalizations: amplitude differences in the wave-forms can be detected in some of the components under the five different conditions. The positive component P_3 is greatest for discrimination (condition 4) whereas during distraction (2,3 and 5) and sometimes during rest (1) this component almost disappears. The negative component N_1 also seems to become smaller under conditions of distraction.

The visual impressions were confirmed by measurements between the peak and trough of components identified in Fig. 1. To find trends in the material, the median and its quartile-deviation were calculated for each component. The results are shown in Table 1. The median amplitude for the first five components (between P_1 and N_3) under condition of discrimination was greater than under condition of rest and various states of distraction.

The Friedman test was used to study the overall effects of each condition. It revealed significant differences in amplitude for N_1 - P_2 ($\chi_r^2 = 23.63$ $P < 0.001$), N_2 - P_3 ($\chi_r^2 = 14.54$ $P < 0.01$) and P_3 - N_3 ($\chi_r^2 = 12.12$ $P < 0.02$).

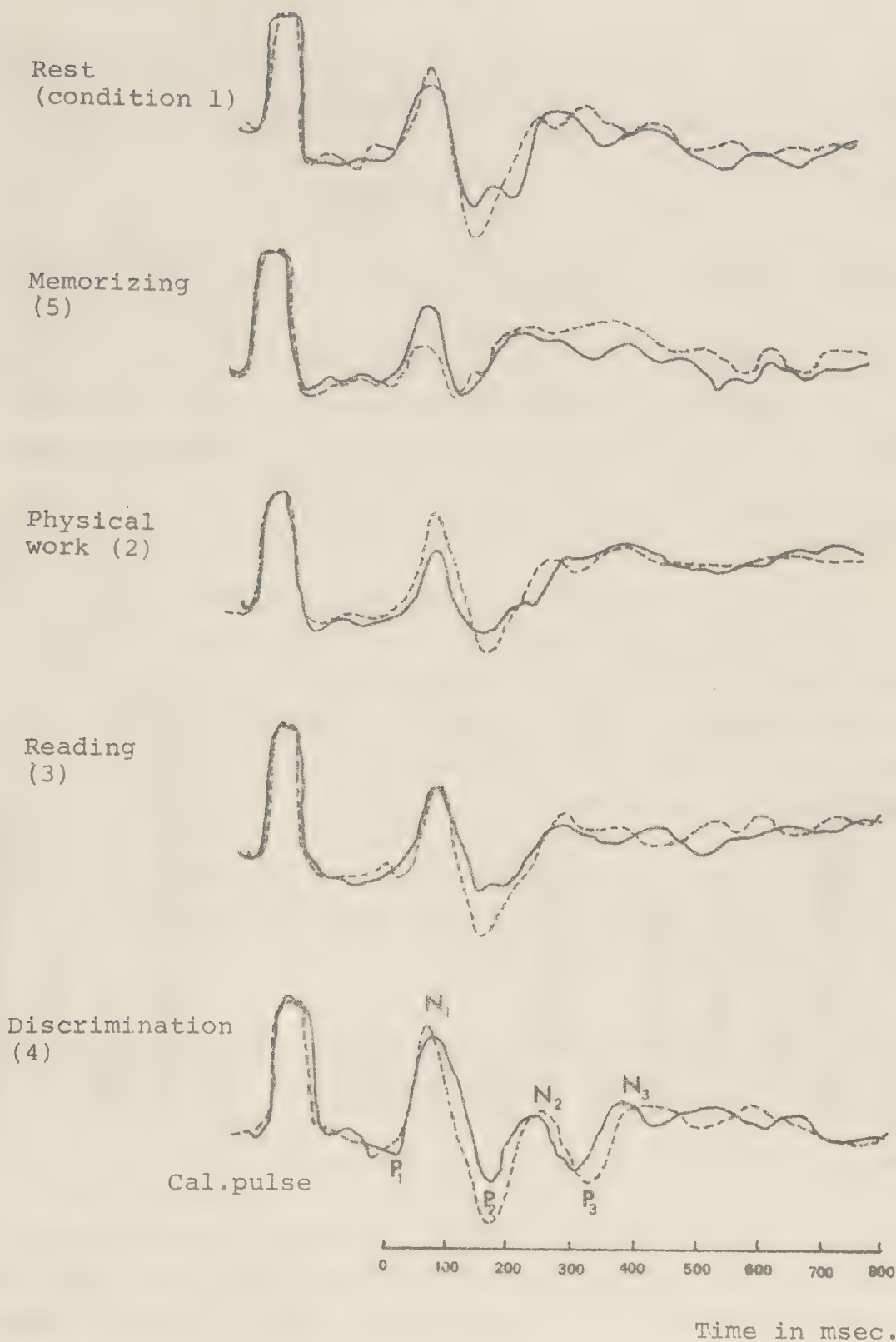


Fig. 1. The curves indicate the superimposed average wave-forms from the left hemisphere of two representative subjects under all conditions. Peaks and troughs are shown in the curves from condition 4. Negative is up and the calibration pulse, in the beginning of each curve, is 10 μ V.

Table 1. Median amplitude and its quartile-deviation ($\pm$) for all AEP-components under the five conditions.

Condi- tion	Component				
	$P_1 - N_1$	$N_1 - P_2$	$P_2 - N_2$	$N_2 - P_3$	$P_3 - N_3$
1	4.57 $\pm$ 1.19	6.34 $\pm$ 1.52	3.09 $\pm$ 1.37	.76 $\pm$.43	1.71 $\pm$.72
2	4.04 $\pm$ 1.59	5.39 $\pm$ 1.51	2.95 $\pm$ 1.19	.61 $\pm$.49	1.54 $\pm$.84
3	4.38 $\pm$ 1.03	5.14 $\pm$ 1.26	2.19 $\pm$ 1.51	.45 $\pm$.34	1.00 $\pm$.51
4	6.01 $\pm$ 1.74	7.16 $\pm$ 1.65	3.71 $\pm$.91	2.00 $\pm$.66	2.59 $\pm$.76
5	3.54 $\pm$.67	4.49 $\pm$ 1.22	3.18 $\pm$ 1.44	.42 $\pm$.23	.45 $\pm$.26

To analyze which conditions contributed to these differences, the Wilcoxon procedure (one-tail test) was applied for all subjects. The amplitude for the components N_1-P_2 , N_2-P_3 and P_3-N_3 were significantly ($P<0.01$) larger for discrimination in relation to rest. Under discrimination the amplitude $N_2 - P_3$ was larger ($P<0.01$) than under distraction in the form of physical work (condition 2). The same was also true of the amplitudes N_1-P_2 and P_3-N_3 . The amplitudes N_1-P_2 , N_2-P_3 and P_3-N_3 were all larger ($P<0.01$) for discrimination than for distraction in the form of mental work (3 and 5).

In sum, the amplitudes N_1-P_2 , N_2-P_3 and P_3-N_3 were larger for discrimination than for rest and all types of distraction.

Further statistical analyses with the same procedure showed which of these conditions of distraction were most effective in reducing the amplitudes mentioned above. The amplitude N_1-P_2 was smaller ($P<0.01$) for mental distractions (condition 3 and 5) and physical distraction (condition 2) than for rest. There were no differences of N_1-P_2 amplitude between the conditions of distraction (Fig. 2a).

The amplitude N_2-P_3 was smaller for mental distractions (con-

dition 3 and 5) than for rest ($P < 0.05$). Physical distraction showed no differences in this amplitude (Fig. 2b).

The amplitude P_3-N_3 was smaller ($P < 0.01$) for mental distraction (condition 3) in relation to physical distraction (condition 2). This amplitude was also smaller ($P < 0.025$) for mental distraction (memorizing, 5) than for reading or rest, and physical distraction ($P < 0.01$). Furthermore the amplitude was not different in magnitude for rest than for physical distraction, but was larger ($P < 0.025$) in relation to mental distraction (reading, condition 3). See Fig. 2c.

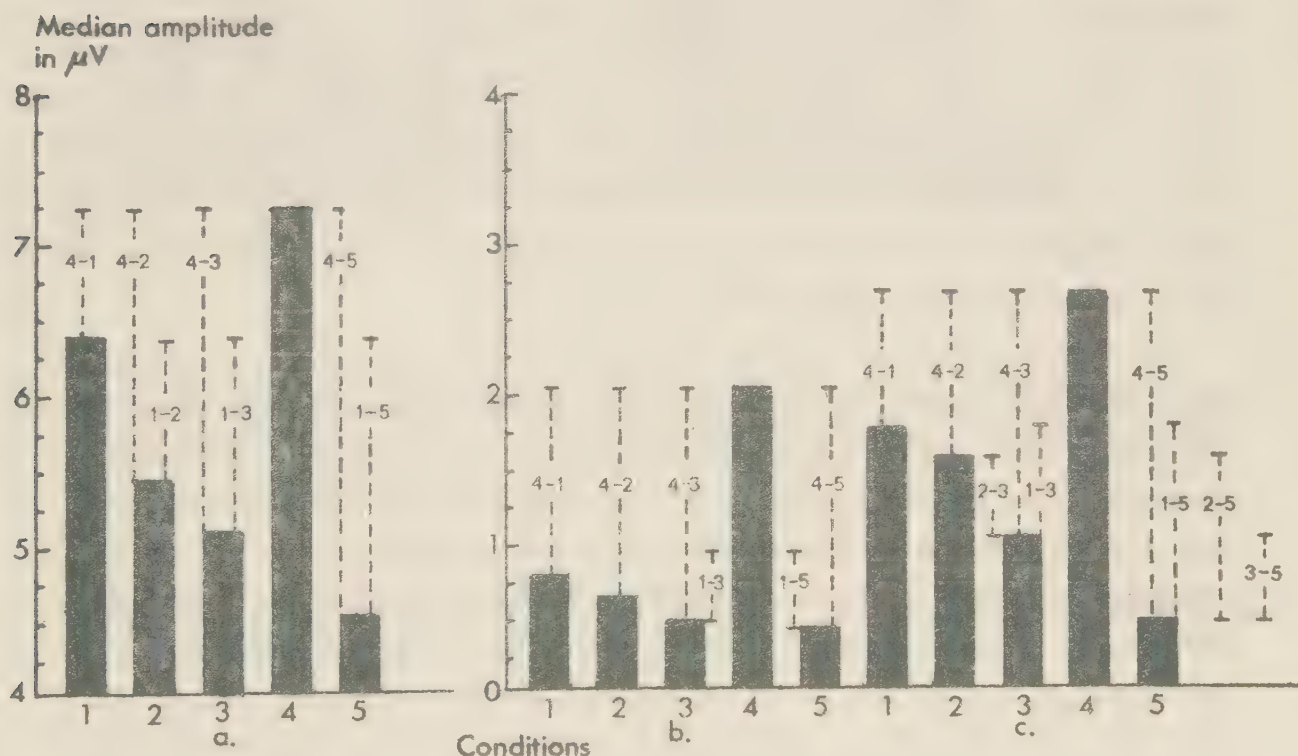


Fig. 2a-c. The dotted lines with reference to the conditions compared ($n_x - n_y$) indicate significant differences in amplitude of AEP-components N_1-P_2 (a), N_2-P_3 (b) and P_3-N_3 (c) between all experimental conditions.

To summarize, mental distraction (memorizing) was most effective in reducing the amplitudes N_1-P_2 , N_2-P_3 and P_3-N_3 . Mental distraction (reading) reduced these amplitudes to a lesser ex-

tent. Physical distraction only reduced the amplitude N_1-P_2 . No significant differences in other amplitudes were found. Fig. 2a-c outlines the significant differences in the amplitudes N_1-P_2 , N_2-P_3 and P_3-N_3 between conditions of distraction, rest and discrimination.

Latency

An overall analysis of variance with the Friedman test brought significant differences between the P_3 -latencies for the five different conditions ($\chi_r^2 = 14.44$ $P < 0.01$ two-tailed test) to light. These differences emanated from the fact that the P_3 latency for discrimination was significantly longer than corresponding latency in reading (Wilcoxon test, $P < 0.005$ one tailed). Furthermore, the P_3 latency was longer for discrimination than for mental discrimination through memorizing ($P < 0.005$) as well as physical distraction and rest ($P < 0.025$). The same latency for memorizing was shorter than for rest ($P < 0.01$) and physical distraction ($P < 0.025$). See Fig. 3a.

The Friedman analysis also showed differences between the N_3 -latencies for all different conditions ($\chi_r^2 = 26.96$ $P < 0.001$). Further testing with Wilcoxon's revealed that the N_3 -latency was longer for discrimination than for mental distraction in reading ($P < 0.005$). This latency was also longer for discrimination in relation memorizing, rest ($P < 0.005$) and physical distraction ($P < 0.025$). Furthermore, it was shorter for memorizing than for rest, physical distraction ($P < 0.025$) and reading ($P < 0.01$). See Fig. 3b.

In sum, the latencies of P_3 and N_3 were longer for discrimination than for all other conditions. Only mental distraction in the form of memorizing shortened these latencies compared with rest. No other latencies changed between different experimental conditions.

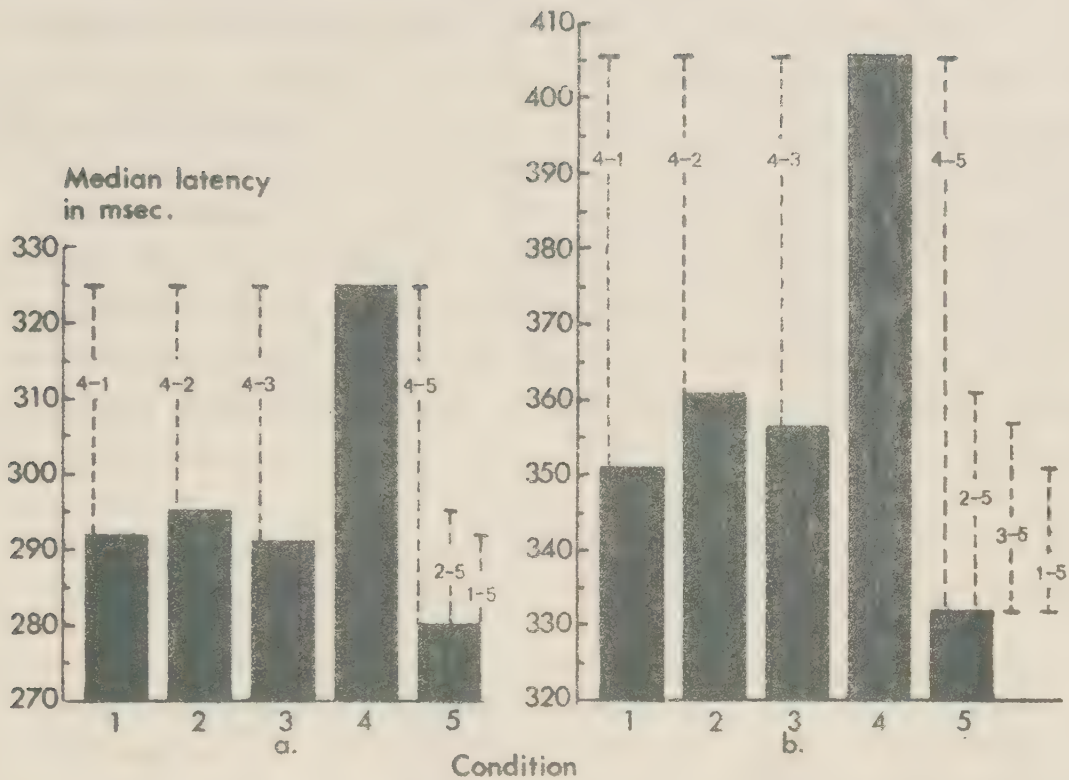


Fig. 3a-b. The bars show median latency of P_3 (a) and N_3 (b) derived from average wave-forms of all subjects in each different condition. Significant differences of latency between conditions are shown as dotted lines with reference ($n_x - n_y$) to the compared conditions.

Summary of alternations in amplitudes and latencies between different conditions

The amplitudes N_1-P_2 , N_2-P_3 and P_3-N_3 were larger and the P_3 and N_3 latencies longer for discrimination as compared to all other conditions. During mental distractions (memorizing and reading) the N_2-P_3 and P_3-N_3 were reduced most, compared with the rest. Furthermore, the P_3 and N_3 latencies were shorter during memorizing than for rest. This was not the case for reading. Memorizing reduced the P_3-N_3 amplitude to a greater extent than did reading. In physical distraction only the amplitude N_1-P_2 was diminished.

Fatigue and effects on amplitude and latency of AEP-components
 Fatigue or habituation may affect the AEP wave-forms during a session lasting fifty minutes. By counterbalancing the order of the different conditions within the session any eventual sequence effects were controlled. To analyze if any effects of presentation order were hidden in the data, a comparison was performed of amplitudes and latencies for two groups of subject. The first group of 10 subjects received a given condition in the first half-session, and the other group of 10 subjects was given the same condition in the second half (Table 2.).

Table 2. Changes in median amplitude and latency of AEP-components owing to presentation-order of experimental conditions.

Condition	Order of presentation in half-session	Median and quartile-deviation for						
		amplitudes in μV :			latencies in msec.			
		$N_1 - P_2$	$N_2 - P_3$	$P_3 - N_3$	P_3	N_3		
1	First	5.66 $\pm$ 1.30	.81 $\pm$.42	1.51 $\pm$.85	290 $\pm$ 12	340 $\pm$ 13		
	Second	5.98 $\pm$ 1.29	.69 $\pm$.35	1.94 $\pm$.57	290 $\pm$ 37	360 $\pm$ 40		
2	First	5.50 $\pm$ 1.44	.45 $\pm$.22	1.30 $\pm$.91	290 $\pm$ 21	365 $\pm$ 42		
	Second	4.96 $\pm$ 1.67	.67 $\pm$.38	1.79 $\pm$.65	300 $\pm$ 40	352 $\pm$ 52		
3	First	5.19 $\pm$ 1.28	.31 $\pm$.10	1.15 $\pm$.67	295 $\pm$ 13	355 $\pm$ 22		
	Second	5.26 $\pm$ 1.49	.64 $\pm$.42	.95 $\pm$.39	285 $\pm$ 29	350 $\pm$ 26		
4	First	6.88 $\pm$ 2.36	1.82 $\pm$.75	2.53 $\pm$.59	303 $\pm$ 21	390 $\pm$ 25		
	Second	7.16 $\pm$ 1.42	2.21 $\pm$.60	2.83 $\pm$ 1.02	335 $\pm$ 20	420 $\pm$ 27		
5	First	4.71 $\pm$ 1.38	.33 $\pm$.11	.54 $\pm$.31	280 $\pm$ 10	335 $\pm$ 9		
	Second	4.00 $\pm$ 1.35	.60 $\pm$.36	.46 $\pm$.15	280 $\pm$ 25	327 $\pm$ 5		

Statistical testing was done with the Mann-Whitney U test (one-tailed test) for groups under each different condition. It produced no significant differences of amplitudes and latencies in AEP-components owing to presentation order for any conditions

($P > 0.05$). Thus, fatigue or habituation did not affect the AEP-components significantly during the experimental session.

Task-involvement

The overall mean heart rate (HR) was used here as an autonomic index of task-involvement. The HR in number of beats per minute was 63, 74, 68, 67 and 72 for the conditions 1-5 respectively. The Friedman test revealed significant overall differences in HR between different conditions ($\chi^2_r = 36.70$, $P < 0.001$).

Further testing with a Wilcoxon produced the following results. See Fig. 4.

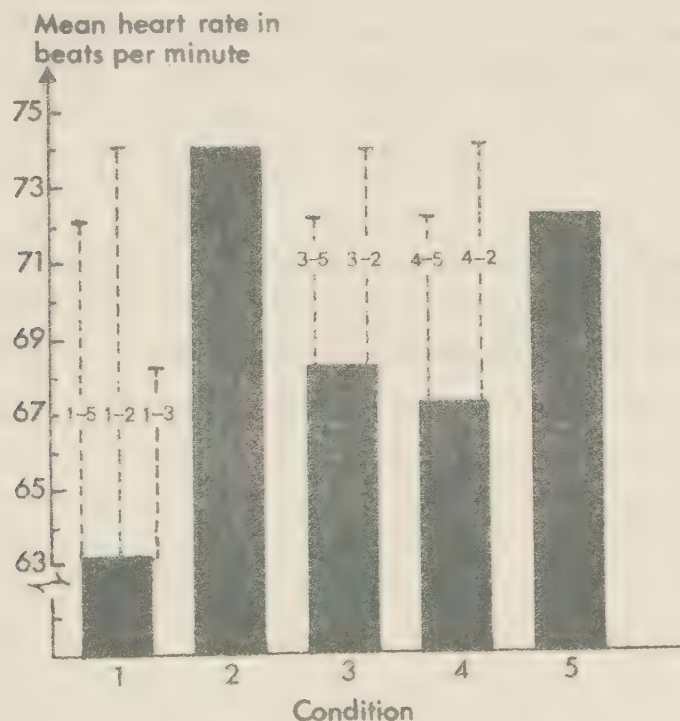


Fig. 4. The dotted lines with reference to conditions compared ($n_x - n_y$) indicate significant differences in mean heart rate between the five different conditions.

For discrimination the HR was not higher than for rest. However, compared to rest it was higher for all conditions of distraction: memorizing ($P < 0.005$), reading ($P < 0.025$) and physical distraction ($P < 0.001$).

For physical distraction the HR was higher than for reading ($P < 0.005$), and discrimination ($P < 0.005$) but not in comparison to memorizing. For this last condition the HR was higher compared to reading ($P < 0.005$) and distraction ($P < 0.025$). It neither differed between reading and discrimination nor between memorizing and physical distraction.

To summarize, the HR was significantly lower for rest than for all types of distraction, but not for discrimination.

Comparisons of amplitude-reduction using speech stimuli and tones

Table 3. Median amplitude and quartile-deviation ($\pm$) for successive AEP components to speech stimuli (S) and tones (T) under four identical conditions. The tone-data are from Hedman (1975).

Experiment	Condition	Component				
		$P_1 - N_1$	$N_1 - P_2$	$P_2 - N_2$	$N_2 - P_3$	$P_3 - N_3$
S	1	4.57 $\pm$ 1.19	6.34 $\pm$ 1.52	3.09 $\pm$ 1.37	.76 $\pm$.43	1.71 $\pm$.72
T		4.50 $\pm$.81	6.80 $\pm$ 2.17	4.14 $\pm$ 1.41	.43 $\pm$.16	1.94 $\pm$ 1.26
S	2	4.04 $\pm$ 1.59	5.39 $\pm$ 1.51	2.95 $\pm$ 1.19	.61 $\pm$.49	1.54 $\pm$.84
T		4.55 $\pm$.79	6.31 $\pm$ 1.23	3.17 $\pm$ 1.40	.32 $\pm$.15	1.23 $\pm$.80
S	3	4.38 $\pm$ 1.03	5.14 $\pm$ 1.26	2.19 $\pm$ 1.51	.45 $\pm$.34	1.00 $\pm$.51
T		4.63 $\pm$.69	6.01 $\pm$ 1.64	2.85 $\pm$ 1.50	.34 $\pm$.10	1.02 $\pm$.60
S	4	6.01 $\pm$ 1.74	7.16 $\pm$ 1.65	3.71 $\pm$.91	2.00 $\pm$.66	2.59 $\pm$.26
T		6.02 $\pm$ 1.26	7.82 $\pm$ 2.25	3.49 $\pm$ 1.63	1.51 $\pm$.63	3.18 $\pm$ 2.07

The assumption that AEP components of verbal stimuli are more attenuated than those for tones under non-attended conditions was tested in the following manner (Table 3): The amplitude differences of all AEP components between the different conditions 1 - 2, 1 - 3, 1 - 4, 2 - 4 and 3 - 4 for all subjects during verbal stimulation was compared to those differences in tonic stimulation. Such comparisons could be made, because the

speech and tone experiments were run in succession to identical task-demands for the different conditions 1-4 as well as with the same subjects.

Testing with Wilcoxon revealed no significant differences of amplitude reductions for verbal and tone AEP components ($P > 0.05$).

D i s c u s s i o n

In general, the N_1 - P_2 , N_2 - P_3 and P_3 - N_3 waves were shown to differ in their amplitude across experimental conditions. They were enhanced for discrimination and diminished for distraction as compared to the condition of rest.

The supplementary condition of memorizing, furthermore, reduced all amplitudes mentioned above most effectively. In this condition the P_3 - N_3 amplitude was even smaller than while reading a text.

These findings are completely in line with results on the AEPs to tones found by Hedman (1975), and hence further support the claim that N_1 - P_2 and P_3 waves systematically fluctuate with the degree of attention allocated to relevant stimuli.

As regards the generality of these AEPs fluctuations, they are shown to occur when pure tones and synthetic speech stimuli are employed. Quite recently Friedman et al. (1975), tracing the AEPs to real speech words and human sounds, 300 msec in duration and with an ISI of approximately 4 sec, found that the N_1 , P_2 and P_3 components changed with these physically identical stimuli which were delivered under three differing conditions of increasing task-demands. The conditions were: a "no task" condition in which the subjects were simply told to listen to the words and sounds. In a vigilance condition, however, they had to discriminate between "signal" and "non-signal" stimuli and only respond to the former ones. The N_1 and P_2 amplitudes -at the left hemisphere electrode- for "signals" under

the vigilance condition were significantly greater than in cases when the words and sounds constituted "non-signals" and "no task" stimuli. The most profound effect was on the P_3 amplitude which increased significantly as a function of increasing task-demands going from "no task" stimuli to "signal" ones.

These results support the data presented here as well as the tone-data presented earlier (Hedman, *ibid.*), and also extend them to cases where human generated stimuli are employed. So far, however, only a few studies bearing primarily on the issue of evoked potential correlates of the cerebral localization of language function have reported the presence of P_3 to stimuli of linguistic nature. Since such studies have been designed to look for the presence of hemispheric asymmetries, their findings do not directly bear on the evoked potential correlates of linguistic processing and will, therefore, constitute the central issue of a subsequent paper.

The hypothesis which was offered here, saying that AEPs to speech stimuli are more diminished under conditions of distraction than the same AEPs to tones, was not confirmed since the reduction of AEP amplitudes was not stronger when relevant speech stimuli were employed under the non-attending conditions as compared to the same amplitudes for relevant tones. Moreover, data from the follow-up interviews revealed that all subjects totally ignored the auditory stimulation while memorizing, whereas two subjects had sometimes listened to the relevant speech stimuli under reading and another two subjects under the condition of physical distraction. In the condition of discrimination, furthermore, they were all totally pre-occupied, but listened less often to the speech stimuli while resting.

A total number of four subjects who gave the relevant speech stimuli attention in the present conditions of distraction was also obtained in the tone-investigation mentioned previously. It could be suggested that the allocation of attention was very

similar in a given condition when speech stimuli and tones were employed.

Basic factors which, according to the process view of AEPs, may influence the activation of psychological processes involved in experiments on attention have been extensively discussed earlier by Hedman (op.cit.). It will therefore suffice to mention here that the process view implies the use of adaptable momentary strategies. They may activate differing types of decisions which are associated with each phase during a process of stimulus discrimination. It is proposed that for the discriminative and rest conditions in the present study, decisions were involved during the phases of (1) is something happening?, (2) what is it?, and (3) is it task-relevant?

In addition, findings from the follow-up interviews as well as the supportive heart rate data seem to suggest that subject used the momentary strategy intended by the experimenter under each condition. Since, furthermore, the interviews did not reveal any fatigue under the test-session and that no fluctuations of AEPs which were due to the presentation-order of conditions were found, the subjects momentary strategy in a given condition was unaffected by between-condition habituation or fatigue.

For the conditions of distraction, however, their strategy was seldom or never adjusted by the experience acquired during the repetitive delivering of each speech stimuli. The main type of decisions involved in these cases were most likely those activated before the classification of the stimulus as being relevant or not was reached at. It is reasonable that the AEPs, but the P_3 in particular, since it has been found to be most sensitive to psychological factors (see Hedman, op.cit.), were effects of strategies and decisions as mentioned previously; hence, of psychological processes occurring before as well as after the onset of each relevant speech stimuli.

The present data also show that the P_3 and N_3 latencies were prolonged for discrimination and shortened for memorizing relative to the condition of rest. The results are consistent with those presented by Ritter et al. (1972) and Hedman (ibid.), indicating that the P_3 and the N_3 latency may be related to the degree of task-difficulty in vigilance conditions.

Here amplitude and latencies of the AEP waves analyzed generated prior to the N_1 - P_2 waves were found to be stable across the differing experimental conditions. Naturally, these preliminary data supporting those given by Picton and Hillyard (1974) and Smith et al. (1970) are not definite evidence of alterations in responsiveness and are hence not a proof which calls the Treismanian attenuation hypothesis into question. This is so because so far there are no unequivocal results showing that the amplitudes of AEPs reflect the amount of neural activity as well as the amount of stimulus-processing. It is also possible that changes in responsiveness -provided they really exist and are substantial enough to generate significant fluctuations of the AEPs- could be reflected by variations in other very early and stimulus depended AEP components which are usually traced by appropriate Hz-passbands in order to reduce the high amplitude low-frequency electrophysiologic "noise".

Finally, subjects may apply attenuation only in certain circumstances, and in particular when they are highly familiarized with the task-relevant stimulus which are in addition regularly delivered. In such cases flexible within-condition strategies are easily adjusted to the experience acquired during the repetitive presentation of stimuli, something which will reduce the utilization of decisions associated with stage 1 and 2 within the process of stimulus construction.

Future studies on intracerebral and cortical evoked potentials, bearing on the central issue of how human attention is mediated, will have to take these alternatives into consideration.

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*Outline of a Process Model of Listening:
Some Implications for the Study of Event
Related Potentials*

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A b s t r a c t. - Discusses current information processing models of selective attention, in particular Shiffrin's view of the changing information flow. An alternative process model of auditory attention is briefly outlined. According to this view, selective listening is dependent on the development of internal structures e.g. the subjective strategies: event repetition, temporal repetition, and alternation strategies. Finally, several implications for the study of human event related potentials - especially the need for single ERPs-analysis - are commented on.

I n t r o d u c t i o n

This paper offers a commentary rather than a review of recent information processing notions of selective attention. An alternative process model will be briefly outlined, which implies that attention is dependent on the development of e.g. dynamic subjective strategies, rather than fixed and separate internal mechanisms. Recent work on human event related potentials (ERPs) indicates that shifts of attention seem to be accompanied by a wide variety of changes in waveform (e.g. Hedman, 1975a, b; Picton and Hillyard, 1974). Such very general changes in cerebral activity support a complex and dynamic view of selective attention. Some ways will be suggested to study the process model of selective listening at both the psychological and neurophysiological level.

The contribution of information-oriented models of attention consists of variations on two basic themes, which may be termed "early-attention and late-attention hypotheses". The common description of processing given in the early-attention models holds that incoming information proceeds automatically up to a level where the physically coded information is temporarily held. This "level" is variously referred to as "iconic/echoic memory" (Neisser, 1967), "pre-categorical acoustic store" (Crowder and Morton, 1969), "S-system" (Broadbent, 1958) or "sensory buffer store" (Aaronson, 1974). At this level of representation the processing of information is believed to cease unless attention is directed towards the input. If the latter happens, higher level processes associated with the short term store

(STS) will be activated, and it is in connection with these that the information acquires meaning (Aaronson's "identifier buffer store", Broadbent's "P-system", and Morton's "logogen system").

The filter-versions of the early-attention models imply that attention is switched between different sources of information. They also assume that only the selected material from one source will at any moment reach the STS for additional processing (e.g. Broadbent, *ibid.*). It is generally believed that unattended information does not undergo such processing. The limitation of processing capacity which occurs prior to the STS is also a major defining characteristic of the other attenuation versions (Broadbent, 1971; Treisman, 1969) of early-attention models. These authors conceptualize the mechanism of attention as the operation of processes determining the relative attenuation of simultaneous information of different kinds. Similar theories also imply that attention affects processing prior to the STS-stage (i.e. Kahneman, 1973; Norman and Rumelhart, 1970).

The assumption that no attentional effects whatsoever occur during the preliminary levels of information processing is the main characteristic of late-attention models. All inputs at these levels are assumed to be processed in an unlimited way by the automatic encoding system. Selection occurs only at the STS- and subsequent levels, i.e. at the central memory level (e.g. Deutsch and Deutsch, 1963; Posner and Rogers, 1978; Norman, 1968; Shiffrin, 1975; Shiffrin and Schneider, 1977).

The following description of information processing is based on Shiffrin's representative model (1975), but differs from it in one important respect. Thus, far more weight is placed here on the successive changes of information at the different stages of processing. The terms, abbreviations, and symbols are supplied by the present author except for the term "stores". which is taken from Shiffrin's terminology.

Flow of information

Information (i), according to Shiffrin, arises both from internal and external sources. He assumes that i is at any time extracted with the aid of processes occurring within the long term store (LTS). This implies, in particular, that the activities of a non-permanent LTS of i , called "long term working memory", and a permanent type of LTS, termed "long term repository". facilitate the extraction of i (Fig. 1).

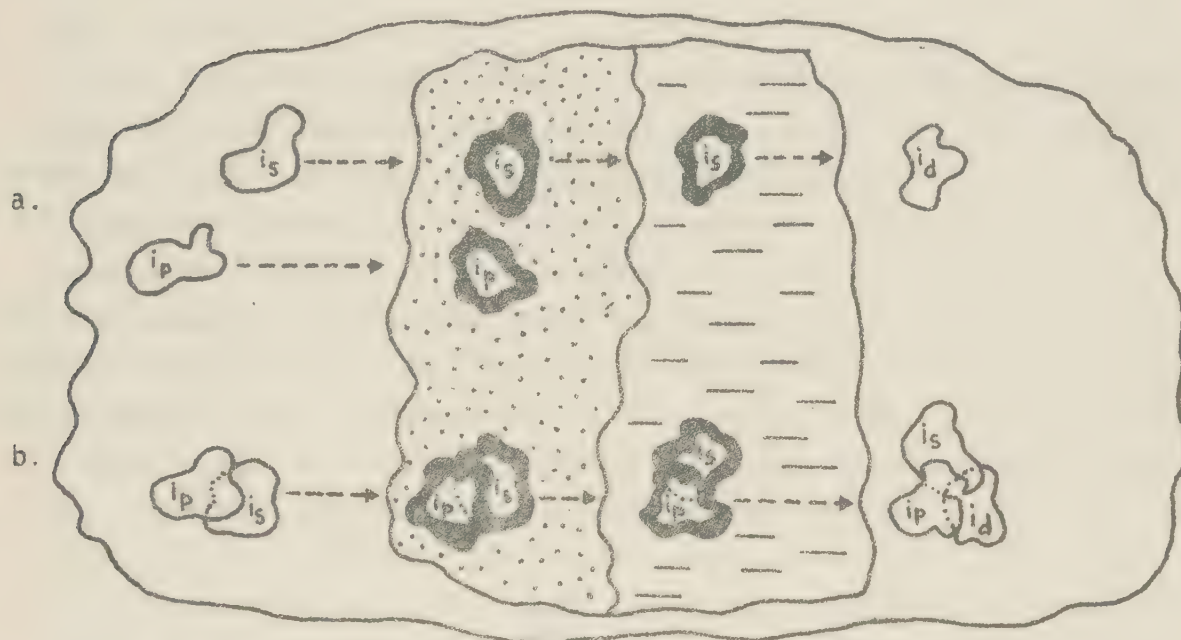


Fig. 1a-b. Schematic representation of the information flow according to Shiffrin's view of attention. (a) The symbols (i_n) represent information at different levels of abstraction. (b) Modified version which shows one case of interference. The symbols represent successive types of stimulus constructions. Unfilled area corresponds to the LT permanent and LT working store: dotted area - the iconic/echoic phase of STS, and hatched area represents the ST working store (see text for further explanations).

This is exemplified in the figure by the symbols i_p and i_s which denote two different kinds of i . The former symbol represents i as analyzed into its essential physical characteristics, whereas

the latter indicates i processed at an higher level of abstraction. Both symbols represent preliminary analyses of i which involve the permanent and non-permanent LTS processes. The extraction of i on different levels and/or from different sources is believed to occur a) in parallel, b) without any limitation of the processing capacity of the system except for certain masking events, and c) probably in an automatic way without the operation of control processes such as attention. During these preliminary analyses i will never reach subjective awareness. This is shown here as lightly outlined symbols of i_p and i_s .

The i , which has been differentially decoded according to its specific features during the preliminary processing, reaches the iconic/echoic type of the STS immediately afterwards. This transfer of i , within as well as between functionally different systems, is shown as arrows (cf. Fig. 1). Extrapolating from Shiffrin's model, i may reach subjective awareness at the iconic/echoic phase. In our example, then, the two different kinds of i get to this part of the STS, and eventually exist there for a few hundreds of milliseconds in subjective awareness. The heavily outlined symbols i_p and i_s indicate this kind of additional processing.

At this moment a particular i , say i_s , is selected for additional processing, and then located in the STS by scanning. Other control processes of attentive nature, such as rehearsal and coding, will prolong the duration of i in the short term working memory and increase the possibility of it being transferred from this temporary store to the permanent LTS. Thus, the STS consists of i at several levels of abstraction. Since, furthermore, attention is seen as the result of accentuation of certain i through the use of serial control processing, selectivity may operate at whatever level controlled processing is taking place. It must not be concluded that automatic processing invariably precedes the controlled one. The two basic processing modes can proceed in parallel with one another, and controlled processing can initiate automatic processing.

When the i_s has been successively transformed to i , which is analyzed into its deep-structure characteristics, it leaves subjective awareness and finally becomes integrated and stored with material in the permanent LTS: i_d . The processing of other kinds of i may be incomplete, however. Here, for example, the i_p reaches the iconic/echoic phase of the STS and may even be represented in consciousness for a few milliseconds: i_p . It is lost, however, to additional analysis because of factors such as spontaneous decay over time.

This late-attention model - as information models in general - does not consider possible effects of interference. But extrapolating from Shiffrin's view, masking and fusion effects might be completely automatic at the initial stage of processing but influenced by voluntary attention at subsequent levels. Within the framework of Neisser's modified information theory (1967) all symbols at the iconic/echoic stage and onwards (Fig. 1b) represent different kinds of stimulus constructions rather than new, complex types of i .

N o t e s o n i n f o r m a t i o n p r o c e s s i n g

All information models of attention assume one or several selective mechanisms underlying attention. Some consider there to be a unitary selective process based upon and occurring after the complete processing of incoming i , whether this processing occur in sequential (Deutsch and Deutsch, 1963; Shiffrin, 1975), parallel (Erdelyi, 1974) or synthetic (Neisser, 1967) fashion. One formulation involves two levels of selection - stimulus set and response set (Broadbent, 1971). Other models consider the possibility of there being several levels of selection (Treisman, 1969; Kahneman, 1973). At the present time no purely behavioural experiments have provided evidence which favours anyone of these formulations.

The principles of attention can only be properly understood at the intersection of converging lines of evidence derived from experimental techniques within several different fields of psychology and several different disciplines. To improve the present state of knowledge on

attention we can study attention as an integral aspect of a general theory of perception, rather than as one or more separate mechanisms operating on information.

According to the late-attention models, all processing of *i*, after a few milliseconds' latency, is dependent upon memory rather than perception itself. But Neisser emphasizes that perception is heavily influenced at all levels by the subject's memories and expectancies. However, his general notion of perception seems to be incompatible with his view of attention implying a preliminary automatic, parallel system (pre-attentive) which is largely unaffected by a later, controllable, serial system (focal attention). The following discussion will focus upon a process model of selective listening which will perhaps make it possible to avoid contradictions and puzzling assumptions.

Recent information theorists define information as stimuli from the subject's external and internal environment, which are elaborated by the aid of internal mechanisms. Thus, *i* is something which can be transmitted, processed, stored and quantified (e.g. Shannon, 1948; Garner, 1974). Most investigators that use information processing or recoding as their basic assumption, consider *i* from external stimuli as a complex of separate physical cues. Internal *i*, which corresponds to previous experiences stored as memories, influences the processing of incoming *i*. When *i* is processed and transmitted between stages and stored in different memories, the *i* will itself become successively transformed, i.e. functionally different from one store to the next.

It is suggested here that a theory of perception with a high ecological validity does not need the supplementary concepts of "processing", "recoding", "extraction", "transformation of information" and "stimulus construction", since information is in the external environment. The subject does not process information since it is objectively present in the e.g. pattern of light reflected from an object. The optic array provides external *i* to be searched for and

selected by the subject (Gibson, 1966; 1978). As compared to Gibson's theory as well as information processing notions, however, the present view of perception takes individual differences into consideration, and describes perceptual learning and selective attention by invoking internal structures, which are sensitive to changes and develop over time.

R a t i o n a l e f o r a p r o c e s s m o d e l

The process model of perception provides a first approximation of how human attention and concomitant event related potentials (ERPs) might be studied. However, our present state of knowledge of both the psychological and neurophysiological aspects of perception is such that this approach can offer no final understanding of the processes in question, and, therefore, includes postulates which are by nature hypothetical and in intent heuristic. Thus, neither a specific model, from which clear-cut quantitative predictions can be made, nor detailed comparisons between the process model and other models will be outlined at this stage. Furthermore, the present model only emphasizes the perception and selection of auditory events in certain experimental situations. As such it considers data from research on serial auditory patterns and discrete as well as serial simple and choice reaction times. In particular, the present approach considers how subjects may perceive rapid as well as slow auditory sequences and patterns. The guiding principles in this endeavour are the following assumptions: (1) Perception is a capacity which develops over time, depending upon preceding experience. (2) Selective attention is dependent on a successive development of internal structures, e.g. subjective strategies, and therefore do not correspond to fixed internal mechanisms.

Before we can understand both the perception of slow sound sequences and rapid auditory patterns the problem of representation of serial order (Lashley, 1951) must be solved. Contemporary explanations based on information processing have emphasized processing time as the important dependent variable (e.g. Aaronson, 1974; Craik, 1973). Only a few alternative theories take into account data suggesting

that subjects also detect and use temporal relations between events to structure their perception of the environment. (Martin, 1972; Jones, 1976). There is also abundant evidence from research on the psychophysical ratio scaling of time, that subjects use individual time scales to respond to timed relationships (e.g. Eisler, 1975). Furthermore, experiments concerned with rhythmic perception show that subjects can identify and preserve the same pattern of relative time even if the tempo - the absolute time values - of speech speeds up or slows down (e.g. Fraisse, 1963; Martin, 1972; Michon, 1978). Other studies show that subjects identify serial patterns very quickly (e.g. Best and Bartlett, 1974). Even in situations where they listen to objectively identical events, which are delivered in a strict regular fashion, they perceive the series as being temporally structured (subjective grouping).

Moreover, other data show that the individual - in certain experimental situations - decomposes the acoustic input and constructs a description of the input as a composite of co-occurring but distinct events. One product of this decomposition is auditory stream segregation (cf. Bregman, 1978). In this case an attended sequence of, e.g. discrete tones, which is presented rapidly at an onset-to-onset-time of less than 1 second - appears to "split" perceptually into two or more parallel sequences as if two or more different sources of non-masking sound were emitted. The splitting becomes more marked when the sequence is played faster. This phenomenon may also be observed with repeating short cycles of speech sounds (e.g. Dorman et al., 1975).

The consequences of stream segregation aside from the subjective experience of two or more streams of sounds as opposed to one, include the inability to perceive the temporal relationships among distinct sounds in different streams or to perceive patterns that cut across streams (Bregman and Campbell, 1971; Dannenbring and Bregman, 1976).

The results of the experiments mentioned above show that in order

to perform such an analysis into streams the person makes use of simple structure for decomposing the input and structuring the stream of events upon which later constructive processes can operate. The effects can be considered as pseudo-automatic since they gradually become preconscious/unconscious (see below, p. 11, (2)).

Genuine automatic effects (see p. 11, (1)) are illustrated in experiments performed by Garner and his collaborators (1974). In these experiments the subjects were not instructed to attend to, and had no foreknowledge of, the binary sequences of buzzes which they were presented with. Yet, they quickly selected a figure-ground relation between the buzzes and then organized the event sequence according to particular rules. Such findings show that subjects spontaneously use very simple gestalt-like rules (based on similarity and proximity) to organize sequential binary patterns. It seems likely that these gestalt-like rules are situation determined with no conscious control by the subject.

Research on discrete, simple reaction times using different randomized inter-stimulus intervals (ISIs), have shown that RTs associated with the shortest ISIs are longer than RTs with the longer ones of the same experimental block (e.g. Drazin, 1961; Klemmer, 1956; Karlin, 1959). Such findings have been explained as being due to temporal expectancy, particularly in cases where the objective probability of the immediate delivery of the imperative stimulus increases as a function of time elapsing after the occurrence of the warning signal (Elithorn and Lawrence, 1955; Nickerson and Burnham, 1969; Näätänen, 1971). According to this variable time-course hypothesis, there is a trade-off function between the duration and intensity of preparation. Recent work (Näätänen and Merisalo, 1977) indicates that temporal expectancy, defined as the subjective probability of the immediate delivery of the imperative stimulus, is the most important determinant of preparation. In general, the stronger the expectancy, the more intense the preparatory state becomes. This is inferred from the fact that the more numerous the posture and peripheral sensory

adjustments which occur prior to the stimulus are, the greater is the facilitation of sensory, motor and central integrative functions in the organism. This conceptual framework accounts quite well for the effects of time uncertainty on discrete, simple RT.

Besides the lack of definite experimental evidence showing that the time-course of preparation is fixed or variable, there are several exceptions to the assumptions (1) that expectancy - the subjective probability of the immediate delivery of stimulus - is identical with the objective probability; and (2) that expectancy affects simple RT indirectly through preparation. Among the several problems which Nääätänen and Merisalo (op. cit.) emphasized, was that their framework does not offer any explicit explanation for results such as the effects of sequential foreperiods (FPs) or ISIs.

Woodrow had already in 1914 observed that, when a particular FP is preceded by a longer one on the previous trial, RT is longer than when the preceding FP is equal or shorter. Such sequential effects may reflect trial-to-trial fluctuations in subjective probability which do not follow alterations in objective probability.

Since Woodrow's first observation, such sequential effects have been repeatedly confirmed, and they have been attributed by some researchers to trial-to-trial changes in strategy (cf. Drazin, op. cit., Karlin, op. cit.). They suggested that the subject may choose a specific proportional length of time to prepare himself for each successive trial. Thus, the subjects seem to expect the arrival of the next stimulus in a sequence of stimuli at the end of an FP of a duration which is identical to that of the preceding FP. According to this expectancy hypothesis, an increase in RT when the present FP is shorter than the preceding one is due to an occurrence of the stimulus prior to the moment at which it was expected. Further research will show if expectancy affects simple RT directly or indirectly through preparation.

Numerous studies on serial choice RT indicate not only an interaction

between adjacent trials (first-order sequential effects) but also higher order sequential effects (Remington, 1969; Falmagne et.al., 1975; see also reviews by Audley, 1973; Kornblum, 1973). Such findings provide good evidence that choice RT on any given trial is sensitive to the pattern of preceding events. Thus, the choice RT associated with a given stimulus, "A", will lengthen with longer sequences of preceding "B's" and shorten with longer sequences of preceding "A's" (cf. Remington, op.cit.).

Since the relevant experimental evidence concerning auditory perception has now been considered, it appears to be in order to put forward some preliminary hypotheses concerning the nature of the listening process. Thus, it is suggested here that the extensive data from studies on discrete as well as serial simple and choice RT just mentioned reflect the following internal structures, which are brought into play when subjects attend to and, subsequently, perceive auditory events. These are:

(1) Immediate, unconscious structures of the kind also described in the literature on sequential patterns (Garner, op.cit.). The function of these structures is considered to be "genuinely automatic".

(2) Quickly developed, preconscious/unconscious expectancy-type of structures which are operative in conditions where short ISIs (i.e. < 1 second) are used. These structures have a "pseudo-automatic" function, since they are initially modifiable and, thus, examples of acquired skills. Bregman (1978) describes similar structures, which seem to have an analogous function in the construction of auditory streams.

(3) Conscious internalized structures which, in the early stages of experimental conditions, where the subject listens to relatively slow sound sequences (ISIs ≥ 1 second), change on a trial-to-trial basis, and whose function is strategic - local subjective strategies. These dynamic strategies can be defined as (a) temporal repetition, - the subjective probability that a specific event will be preceded by

an interval of the same duration as the one preceding the previous event, (b) event repetition, - the subjective probability that the nextcoming event will be identical to the preceding one, and (c) alternation - the subjective probability that a given pattern will continue to alternate. For example, in a choice RT condition with random presentation of stimuli and ISIs, the subject may develop a specific, subjective probability that alternations of events and intervals will continue (genuine alternation) that the same alternation patterns of events will recur (event alternation), or that the alternation of intervals will continue (temporal alternation).

(4) Anticipatory structures which will (a) successively function at a preconscious level when events in a series cease to be attended to during the person's continuous scanning, and (b) gradually become preconscious in the late stages of experimental conditions employing long ISIs (i.e. > 1 second), owing to habituation.

(5) Internal representations at a conscious level - global subjective strategies - which are controlled and changed from one condition to another by the experimenter's instructions. Such "a priori strategies" involve the systematic variation of a) a priori "temporal expectancy" or its counterpart, "time uncertainty", and b) a priori "event expectancy", or "event uncertainty".

In the remainder of this paper a simple descriptive model of listening in a serial-RT task shall be outlined, together with some of the implications of this model for research on human event related potentials during selective listening.

Processes listening in a serial RT - situation

In ordinary life a person's listening is determined by a complex of mental processes and objects, events in the situation. He explores, selects, and integrates information about these events from several sense modalities. By continuously selecting information - in the Gibsonian sense (Gibson 1966, 1978) -, which to begin with resides briefly in a unique sensory store, he is able to develop

internal structures to deal with this incoming information (see structures of types 2-4; also, the subsequent discussion of these). Internal structures are perceptual, not auditory, and types 2-4 are continuously being modified by new information. Thus, the subject develops, through learning, a complex of differing internal representations of events which partly direct the ongoing perceptual process. However, these structures - in certain contexts referred to as subjective "strategies" - are no control processes, in the sense in which this term is used by Erdelyi (1974) or Shiffrin (1975), since they (1) develop over time, (2) do not comprise a superordinate control of perceiving, and (3) do not manipulate any internal flow of information. According to this alternative to current information processing models of attention, the subject does not attend to sensory inputs, but to events and objects in the environment. Such a process of attention is positive (no filtering, blocking, attenuation etc.), since the subject selects what he wants to hear by actively engaging himself in it.

It is suggested that just as the optic array is specific to the identity, location, motion etc. of an object in the environment (Gibson, op.cit.), the acoustic pattern is specific to auditory events. This idea of an "acoustic array" has also been recently advanced by Jones (1976) and Neisser (1976). Presumably such patterned acoustic information can be detected only if the subject knows how to listen for it, i.e. if he has developed the proper structures. The chief characteristic of the concept of subjective strategy, as advanced here and previously (Medman, 1975a, b), is its description of the way we anticipate (are primed or tuned to) auditory events.

Figure 2 presents in more detail the process view of listening. In this standard, serial choice RT task, the untrained subject is instructed to listen and respond to relevant sounds ("A"), which occur irregularly ($P=.5$; ISIs >1 second) in a binary sequence of supra-liminally delivered sounds (200 msec tones "A" and "B" at 70 dB SPL and of 1000 Hz and 1100 Hz, respectively). The duration of this experimental conditions is 5 minutes.

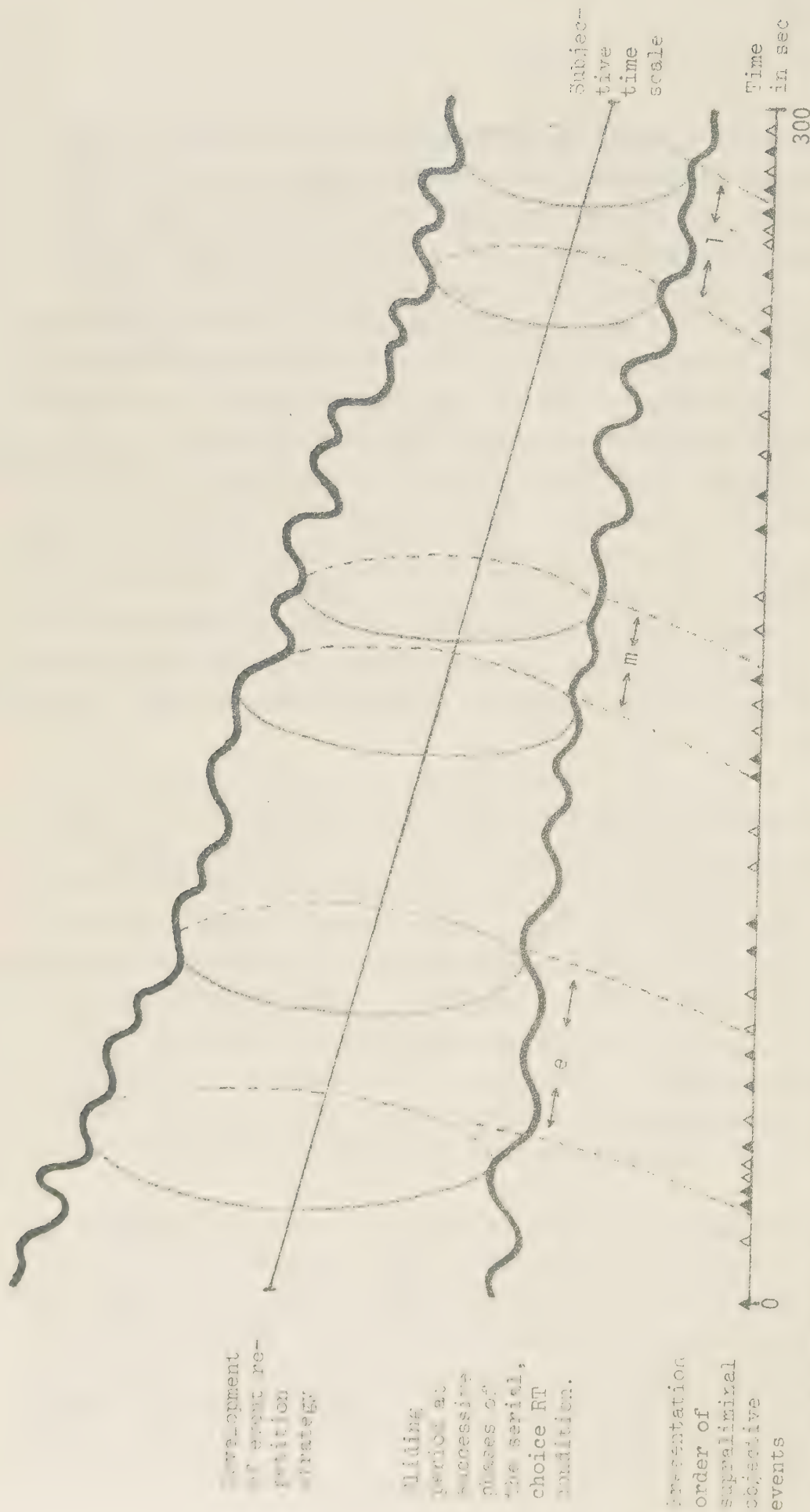


Fig. 2. Schematic illustration of the process view of selective listening in a serial, choice RT task. Relevant tones "A" (Δ), and tones "B" (Δ), constitute a binary sequence of events of 5 minutes duration. Internal structures are assumed to develop, i.e. be successively differentiated, during a cyclic macro-process of listening. This on-going decision process, here represented by the event repetition strategy, is shown as a fluctuating formation (between thick lines) along a subjective time scale. The length of the sliding period (arrows between dotted lines) is also assumed to vary, thus encompassing a different number of events during the early (e), medium (m) and late (l) phases of the listening condition. Processes discernable on the micro-level, i.e. "post-stimulus" decision making, may become rapidly superseded by the on-going decision process (see text for further explanations).

Since listening is a temporally extended activity, the subject continuously develops more or less specific internal structures (2-4). These are based partly on the acoustic information in the environment (objective supraliminal information) and partly on information already acquired. As there is always some degree of uncertainty involved in the development of such structures, they never reach total specificity. For example, they develop from being undifferentiated to being relatively differentiated, but remain, at the same time, in a state of continuous fluctuation.

At initial stage of the present condition, the subject presumably, makes use of several structures simultaneously, i.e. 1, 3a,b,c, 4a and 5. For the sake of simplicity, figure 2 only shows the successive differentiation of the event repetition strategy (3b) from the early to the late parts of the experimental condition. This continuous transformation of a (conscious) event-repetition strategy into a highly differentiated preconscious event-repetition structure (4b) with increased practice on the present selective listening task, is one example of "within-condition" habituation (Hedman, 1975a). What is proposed here is that the transformation of structures can be both from conscious to preconscious and vice versa.

Recent work in perception has provided evidence that successive events, here sounds A and B, are perceived as independent only when they are separated by at least 150-250 milliseconds (e.g. Kahneman, 1973; Posner, 1975). In the example considered earlier, A and B are perceived as independent, because the ISI is greater than 1 second. In order that the identification of separate events - As and Bs - as well as the construction and reconstruction of internal structures, is possible, the sequences of As and Bs must be preserved over a period of time which is long enough to permit earlier parts of the sequence to be modified as later events occur. The length of this "sliding period" varies with the span of the subject's attention. When all successive events in a series are focally attended to, the period constitutes the "specious present" (James, 1890). The availability of events during such a period presumably depends on the

function of the sensory store and some short term store. In general, all structures described by the process model of listening are dependent on memory, since ordinary perception is an activity which extends over time.

The sequential effects in serial simple and choice RT experiments seem to support the idea of a sliding period. Trial-to-trial changes in event repetition strategy during the sliding period are likely to be dependent on (1) the number of events, (2) the structure of events in the series (their order) as well as other, at the present unspecified factors. For example, the more frequently a particular sound occurs within this period, the greater is the subjective probability that the event will recur on the next trial - (trial-to-trial differentiation of event repetition strategy). The overall mental structure is seen here as a multidimensional, organized, general system of processes, which includes the full range of internal events, and it is by means of these factors that the subject manifests, on the one hand, his internalized structure and, on the other hand, his behaviour. It should be apparent from this definition that a given substructure is embedded within a more inclusive structure. This means that in our example, the event repetition strategy is at each moment itself influenced by other substructures (temporal repetition, and alternation strategy).

Most of what has been written in this section has been devoted to a discussion of the macro-process of listening. The processes involved during listening are also discernable on the micro-level. But it does not seem desirable to go into these at any greater length, especially since some of them have been discussed elsewhere (Hedman 1975a). However, to summarize briefly the author's opinion about these micro-processes: Strategies also involve decisions made during the discrimination of a single event in a series of auditory events. At least three types of decisions may differentially affect the process of stimulus discrimination in detection tasks. These decisions are the ones invoked during the answering of following questions: (1) Is something happening? (2) What is it? (3) Is it task-relevant?

It is likely that such decisions are differentially involved during the discrimination of a specific sound in a sequence ("post-stimulus" decision making) at different stages of a given experimental condition. This would mean, in our example, that most of the decisions should be made during a sliding period which covers the initial phases of the condition. At later phases, when perhaps only a few, differentiated structures (e.g. 4a,b) are used, very few if any decisions will be made during each discrimination of events A and B. Thus, selective listening can be reinterpreted in such a way that it is seen to be an ongoing decision process, in contrast to the kind of the decision making which occurs after the stimulus has been presented ("post-stimulus" decision making). It is suggested that the former activity rapidly supersedes "post-stimulus" activity and is therefore considered to be more representative than the latter in the type of experimental situation that we have here.

When a subject discriminates a specific event in a series of the kind used in the condition discussed here - selects a supraliminal, objective event - he makes use of internal structures which are integral phases of the ordinary macro-process of listening. He is engaged in a selection process which results from the organization of his subjective structuring of events. All kinds of perceptual information are potentially important in this monitoring task, but the subject listens only for specific patterns in the auditory sequence. What he listens for is whether the objective sequence of events A and B are incongruent or not with his existing structures.

When the delivery of events A and B is delayed or interrupted - i.e. during the ISIs - the construction and reconstruction of internal structures will continue. The same reasoning also applies to selective listening conditions, where subliminal stimuli are presented. It follows that the subject will occasionally anticipate events for reasons that may have very little or nothing to do with the objective experimental sequence of events.

To conclude, selective listening in a serial RT task is viewed as

complex skill, involving mental processes prior to, simultaneous with, and following the occurrence of a specific auditory event in the series. Selective listening is dependent on the development of internal structures, as well as discrepancies between objective events in the sequence and existing structures, rather than regulated by separate, fixed mechanisms which manipulate and control a flow of information.

In the context of the present model, these subjective structures are embedded in more inclusive structures. Further study is required in order to examine whether the various dynamic structures develop simultaneously or serially during the performance of an experimental task, viz. whether mental processes during selective attention occur in series or in parallel (Norman and Rumelhart, 1975).

As the subject's task in the serial RT situation is very similar to tasks used for the study of human event related potentials (ERPs), we shall, in the following section, discuss some implications of the process model for research on ERPs during selective listening. Particular emphasis will be placed on the global "a priori strategy", termed "time uncertainty", and local subjective strategies.

P r o c e s s l i s t e n i n g i n t h e E R P - s i t u a t i o n
It is by now a well established experimental fact that the global "a priori strategy" - as studied by variations of a priori time uncertainty or its counterpart, a priori temporal expectancy - is one determining factor for the elicitation of different average ERP waveforms (e.g. Schafer and Marcus, 1973; McCarthy and Donchin, 1976). Schafer and Marcus varied their subjects' foreknowledge of stimulus (1-msec clicks at 80 dB) timing, by using a random, subject-initiated stimulus condition (no time uncertainty) and a machine-triggered condition (great time uncertainty). They reported that the average amplitudes of all later ERP components, whose latencies exceeded 100 msec (including the P300 wave), were significantly larger when components were elicited during the condition of great time uncertainty. Using a similar machine-stimulation condition, McCarthy and

Donchin (op.cit.) also found that greater a priori temporal uncertainty is related to greater N140 amplitude.

In order to assess and compare such findings, more systematic study is required, as a priori time uncertainty is, unfortunately, a diffuse independent variable. The reasons for this are the following: (1) The subject's accuracy of time judgment (in absolute units of time) generally decreases the longer the interval to be estimated. (2) The subjective time uncertainty does not mirror the objective distributions of intervals presented by the experimenter. (3) Temporal uncertainty is not identical in comparing experimental conditions which are comparable in that they have the same mean intervals, but have different ranges of intervals, since the distributions of intervals may be unequal in the conditions. For example, in Schafer and Marcus' study, the mean ISI in the machine-triggered condition was about 2000 msec, and in McCarty and Donchin's study the mean ISI varied among subjects from 4140 msec (s.d.=1104) to 8634 msec (s.d.=1575). In these two conditions, the means of ISI, ranges of ISI, and their distributions differed. We can, therefore, assume that the subjects' time uncertainty was quite different. Further investigations along these lines might include: (1) Assessment of the role of well defined "a priori strategy", i.e. temporal probability, on the ERP waveform over a wide range of temporal probabilities. (2) Examination of serial factors within sequences of events by e.g. control and manipulation of the range of intervals as well as the distribution of intervals. (3) Estimation of the interaction of the former global, subjective strategy and the latter sequencing of intervals.

To eliminate pre-stimulus events, such as differential preparedness (Näätänen, 1970), in the ERP-condition, investigators use the method of randomized presentation of stimuli. Single-trial waveforms are collected, depending on which stimulus occurred, for averaging on- or off-line. The basic assumption underlying this technique is that, when stimulus and task variables are held constant, the single ERPs elicited by all occurrences of a given event are identical. But the validity of this assumption of homogeneous single ERPs has been

increasingly questioned (Donchin, 1969; Hedman, 1975a,b; Näätänen, 1975). Systematic trial-to-trial fluctuations of the waveform of single ERPs may occur, presumably due to pre-stimulus events (i.e. variations in the sequence of events preceding the eliciting stimulus).

According to the process model of listening, which is substantiated by, for example serial RT data, the subject develops internal structures during experimental conditions where stimuli are regularly and randomly delivered. One important factor of trial-to-trial variations of subjective structures may be found in the micro-structure of the successive ISIs. Moreover, just as the serial RT is dependent upon the sequence of preceding trials, so it may well be that serial factors are involved in the single ERP-waveform. It is suggested that a given set of ERP data exhibits sequential effects under the following conditions: (1) If a subset of single ERPs can be segregated from a series of consecutive single ERPs on the basis of the particular relationship that each of these selected single ERPs bear to their predecessor(s), i.e. if definite patterns can be isolated in the stimulus series. (2) If the data for that subset differ significantly from the rest of the single ERPs and average ERP.

In 1975 the author did a few pilot studies with a view to finding some indication as to which patterns in a sequence of stimuli, presented to experimental subjects, were associated with different subsets of single ERPs subsequently obtained. The aim of the studies was, in particular, to ascertain whether different single peak-to-baseline N100 amplitudes, derived from scalp and intra-cerebral electrodes, were related to specific subsets of ISIs (Hedman, 1975c). As the studies were only exploratory, and only a limited sample of ERPs from one subject was obtained, no statistical analyses of the data were attempted. However, it is instructive to examine briefly, in the present context, the micro-structure of one listening condition in which the sequence of ISIs was systematically varied.

The examined data were single ERPs recorded from one normal subject aged 35 years. Intra-cerebral electrodes were located at C_4 (frontal) and C_{12} (parietal), and each electrode was referred to linked mastoids. An electrode attached to the forehead served as the ground.

The epoch was 1000 msec, and 400 msec preceded the stimulus. A PDP 12 computer was used to store single ERP data on magnetic tape, and to average the EEG data off-line. The timing of the stimuli was done by the same equipment. Information about apparatus, subdural electrodes, and the precautions taken against eye-movement artefacts has been described elsewhere (McCallum and Walter, 1968; Papakostopoulos et al., 1975).

A series of 91 identical auditory events was presented through a pair of headphones (TDH, 10 ohm). The events were 2 msec clicks of 1000 Hz at 70 dB SPL. As in the machine-triggered condition used by Schafer and Marcus (1973), and later by McCarthy and Donchin (1976), the same stimulus was presented repeatedly and no task other than listening was required.

As seen in figures 3a the distribution of ISIs was serially patterned. "Actual" ISIs were here defined as those intervals which were terminated by stimuli eliciting the single ERPs for analysis ("selected" single ERPs). The "actual" ISIs of 4, 8 and 16 seconds duration always followed two longer "preceding" ISIs. The ISI-patterns were randomly distributed and repeated 5 times in order to collect reliable single ERPs. There were a total of 6 different ISI-patterns; 3 with small differences in seconds between "actual" ISIs and two "preceding" ISIs (the patterns 5, 5, 4; 10, 10, 8 and 20, 20, 16 sec), and 3 with large differences (10, 10, 4; 20, 20, 8 and 40, 40, 16).

It was suggested that large differences in seconds between "actual" ISIs and "preceding" ISIs would be associated with large N100 amplitudes of "selected" single ERPs, and vice versa. Trends in the predicted direction were found for all single ERPs. For example figure 3b shows single N100 amplitudes associated with the "actual" ISI (4 sec) both when the difference between this and "preceding" ISIs was small (1 sec for pattern 5, 5, 4) and when it was large (6 sec for pattern 10, 10, 4). The parietally recorded N100 wave was larger (32.0 μ V (small diff.); 57.0 μ V (large)) than the frontally recorded one (21.0 μ V (small diff.); 31.8 μ V (large)).

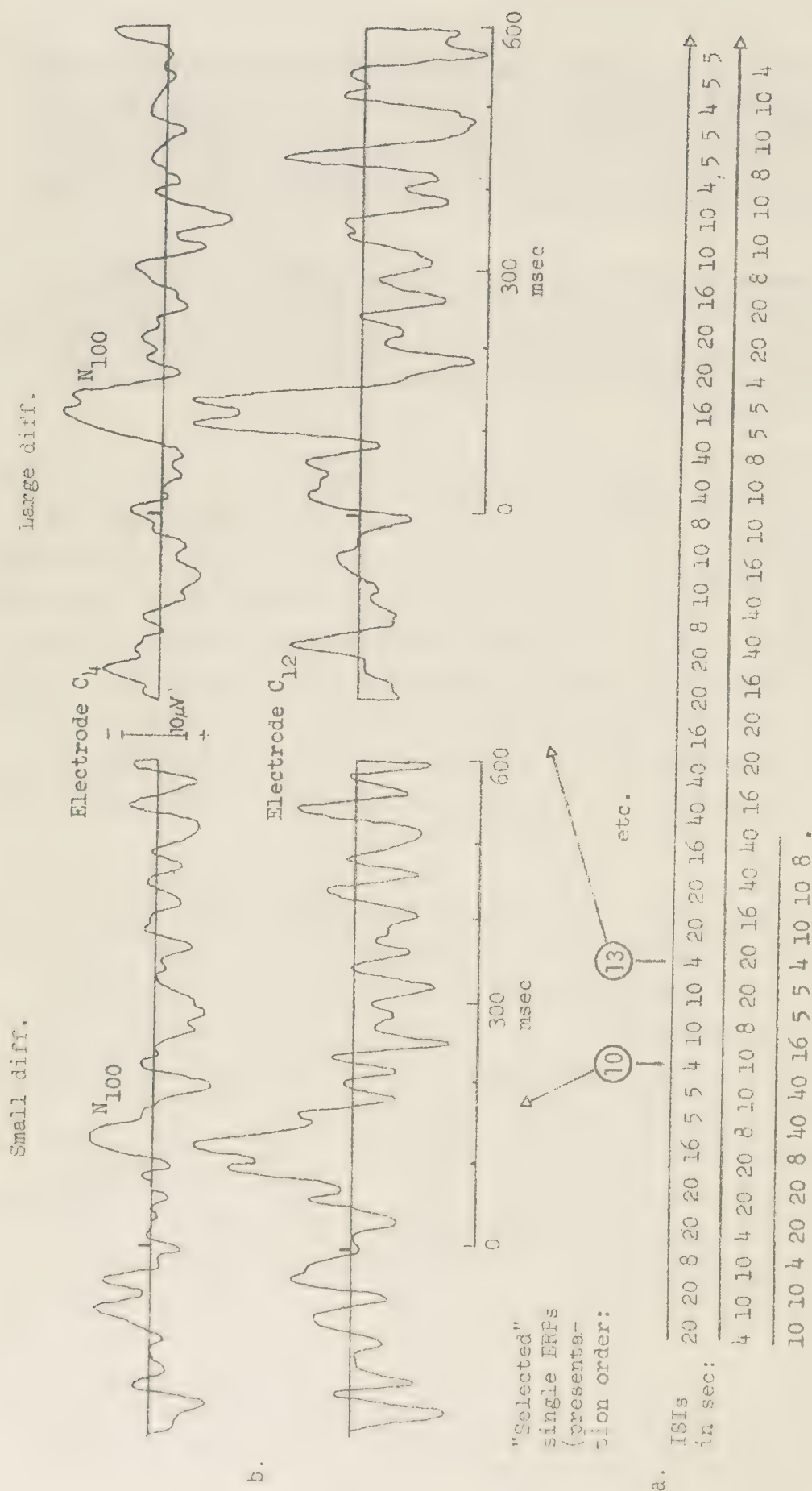


Fig. 3a-c. Presentation order of identical clicks, patterning of ISIs, and single N_{100} -amplitudes. (a) Selection of single EPPs, associated with the "actual" ISI (4 sec), for small and large differences in seconds between this interval and two "preceding" ISIs. (b) Curves from frontal (C_4) and parietal (C_{12}) electrodes showing a trend which implies that "selected" single N_{100} -amplitudes are small ($n=5$) when the differences between "actual" ISI (4 sec) and "preceding" ISIs are small.

The frontal mean N100 amplitude ($n=15$) for all "selected" single ERPs were $19.0 \mu\text{V}$ for small (1,2, and 4 sec) differences between "actual" and "preceding" ISIs, and $26.6 \mu\text{V}$ for large (6,12, and 24 sec) ones. Corresponding values for the parietal N100 wave were $48.4 \mu\text{V}$ and $57.4 \mu\text{V}$. This trend was strongest for the single N100 amplitudes associated with the "actual" ISIs of 4 seconds duration.

The trend shown in these preliminary data supports the view that trial-to-trial fluctuations in amplitude of the N100 waveform observed in a subset of single-click ERPs might be attributable to specific ISI-patterns in the stimulus series. Naturally, further research is required to test (1) if the data for subsets of single ERPs (both early and late components) differ significantly from other subsets as well as average ERPs, and (2) if the trial-to-trial fluctuations of single ERPs are associated with trial-to-trial changes during the development of the subjective structures mentioned previously (see pp.11-12).

It is further indicated by the results of the pilot study that a detailed study of "within condition" habituation is required. Experimental conditions containing stimulus sequences of long duration (the sequence in the pilot study lasted 1270 sec) should then be compared with conditions containing short sequences (e.g. 30 sec). Furthermore, small and large differences between a specific "actual" ISI and "preceding" ISI can be studied in separate experimental blocks of trials. Shorter "actual" ISIs (i.e. 0.5-4 sec) can be used. Different "a priori" strategies can be experimentally manipulated between different conditions, etc. In short, the experimenter can facilitate the development and influence function of different subjective internal structures and concomitant fluctuations of single ERPs during different selective listening tasks.

In addition to such studies of temporal sequential effects in single ERPs, detailed analyses of event sequential effects in the ERP waveform are needed. Serial RT data (cf. Falmagne et al. 1975; Remington, 1969) show that subjects attribute unwarranted serial dependency to

random sequences of auditory events. Thus, in a series of constant a priori "event probability" (or its counterpart "event uncertainty"), the subjective probability may fluctuate considerably in a trial by trial manner. It is well known that the a priori probability of a task-relevant event affects the waveform of the ERP (e.g. Donchin et al., 1973; Squires et al., 1977; Tueting et al., 1971). The more unexpected or rarer the event, the larger the P300 amplitude. Since this amplitude may be affected by trial-to-trial variations in subjective probability, despite that the a priori probability is fixed in a given block of trials, it is appropriate to consider the serial patterning of preceding events in selecting trials for averaging.

Recent findings by Squires et al. (1976) indicate that the waveform of the ERP is remarkably sensitive to trial-to-trial variations in the sequence of stimuli preceding the eliciting event.

In this study, seven subjects listened to series of regularly delivered (ISI=1300 msec) tone bursts (60 msec, at 60dB SPL). On each trial the tone was either high-pitched (1500 Hz) or low-pitched (1000 Hz) and equally likely to occur ($P=0.5$). The subjects counted the high-pitched tones silently and reported the count after each block of 200 trials. In a second condition, the global a priori stimulus probabilities were changed to 0.3 (high-pitch) and 0.7 (low-pitch). Each subject listened to a total of 800 tones in the first and 1600 tones in the second condition.

In the usage of Squires and his collaborators terminology an "A" represents whichever target stimulus occurred on trial n (cf. Remington op.cit.). The ERP for this first-order sequence represents the average from all occurrences of the target stimulus, A (i.e. the high-pitched tone), regardless of the preceding sequence. There are four possible patterns of stimuli on trials $n-1$: "AA", "BA", and "BB", "AB". The ERPs for these second-order sequences are formed from trials on which A was preceded by A, from A trials preceded by low tone trials (B) and vice versa. Similarly, there are eight third-order, 16 fourth-order, and 32 fifth-order sequences. When the sequences terminated with a "B", they reversed the labels.

These results, which show the effects of stimulus sequence on the ERP-waveform, are analogous to the serial RT data reported by Remington (op.cit.) and Palmagne (op.cit.), showing that the RT for "A" is pro-

longed with longer sequences of preceding "B's". Figure 4 shows the average ERP-waveforms from the vertex lead for one subject for 9 different event sequences, which form the upper and lower limbs of the RT tree structure reported previously (Remington, op.cit.).

The amplitude of the P300 complex (N200, P300 and slow wave components) was enhanced by longer sequences of preceding "B's", and decreased with increasingly long runs of "A's". This effect was found to extend to trial $n-4$. Furthermore, the amplitudes for each sequence were larger for events with a low a priori probability and smaller for those with a high probability.

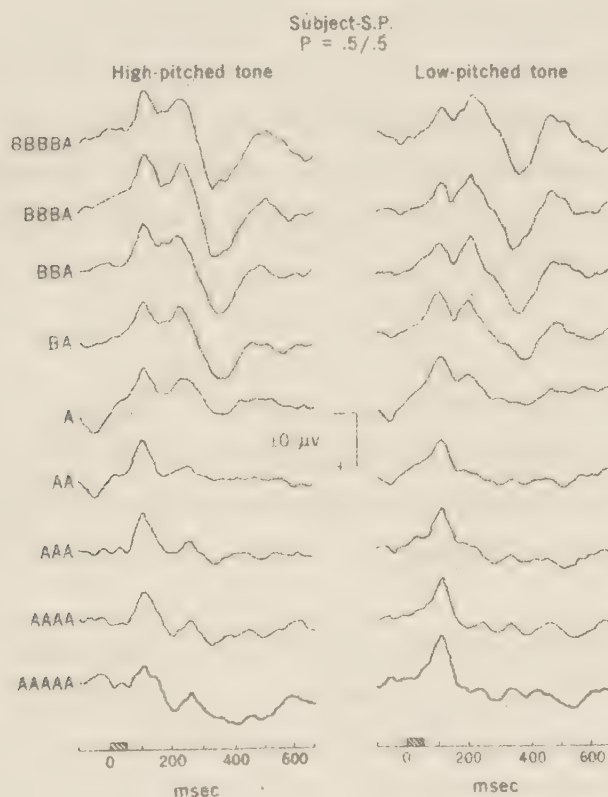


Fig. 4. Averaged ERP waveforms from the vertex (C_2) lead from one subject in the first condition for sequences that form the outer limbs of a tree diagram with the probabilities of occurrence of each signal equal to .5. Vertex negativity is plotted upward. The size of the P300 complex elicited by stimulus "A", increases with the number of "B's" that precede it. The size of the P300 complex decreases as runs of "A's" of increasing length precede a specific "A" (from Squires et.al., 1976).

The present process model can be used to estimate a variable of "overall subjective probability" of an event; the probability here being a function of the preceding sequence of events. The estimate thus derived can then be used to describe the findings of sequential dependencies in ERP waveform (e.g. Squires et.al., op.cit.). It is suggested that this variable reflects the combined effects of several internal structures, i.e. the event- and temporal probability types of "a priori strategies" (see p. 12(5)) and transient, subjective probabilities (2; 3a,b,c; 4,ab). The higher "overall subjective probability" associated with specific event on a given trial, the smaller the amplitude of the P300 waveform which is elicited on the trial. In particular, when a nextcoming event in a sequence, occurring within a given sliding period, is congruent with an event repetitive strategy (3b and 4b) the amplitude of the single ERP is smaller than when the event is incongruent. More systematic studies of subphases seem appropriate for future single-trial analyses of ERP data, since both the types of internal structures, as well as their degree of differentiation, might be different during early and late phases of the experimental condition.

S u m m a r y a n d c o n c l u s i o n s

The process model implies that selective listening, instead of being regulated by fixed mechanisms, is dependent of internal structures, as well as discrepancies between objective events in the series of events and existing structures.

Selective listening is an on-going decision process by which the subject interacts with his experimental environment. It is analogous to Donchin's (1975) view that the human nervous system "continuously generates hypotheses about the environment, which are then validated against the input information (p. 213)".

It is proposed that this empirical decision process corresponds to the subject's estimate of probability (cf. also Laming, 1973). This probability estimate is updated from trial to trial, and is, therefore, a function of the patterning of the preceding sequence. Squires

tial interactions in choice RT data indicate that the subject constructs probabilities from the recently presented sequences of events.

According to the process model of selective listening the variable, "overall subjective probability", is determined by several internal structures. For example, during a specific sliding period, the memory of recent occurrence of target "A" in a sequence may increase the subjective probability that "A" will recur (event repetition) after a similar interval (ISI) as that which separated the immediately preceding event from events which preceded it (temporal repetition). Subjective probability may also increase if "A", ISI, or both fit the alternation pattern (event-, temporal-, and genuine alternation, respectively). The overall subjective probability is also influenced by the global a priori probability that an event will occur (a priori event probability). Recent findings show that both a priori event probability and sequential constraints of preceding stimuli determine the amplitude of the P300 complex (Squires et al., 1976; Dunchan-Johnson and Donchin, 1977). More research will indicate (1) if these two effects are independent, (2) if a priori temporal probability also influences overall subjective probability as well as the amplitudes of ERPs.

There are several implications for future ERP-research. Especially, the basic assumption that all single ERPs associated with a particular event are homogeneous seems untenable.

Further research is required to test the assumption that trial-to-trial fluctuations in single ERP waveforms - e.g. the P300 - are associated with transient changes of subjective probabilities. If this turns out to be the case, current interpretations of ERP findings in terms of the amount of information processing on a specific trial (e.g. Ruchkin and Sutton, 1978) and decision making during the discrimination of events (e.g. Kutas et al., 1978) must be seriously reconsidered. It is hoped that the empirical findings and theoretical considerations put forward here may then prove useful, in providing an alternative model which is capable of explaining subjects' ability to learn and adapt to tasks of selective listening.

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